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BRITISH CHEMICAL ENGINEERING

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THE JOURNAL DEVOTED TO THE TECHNIQUES OF CHEMICAL ENGINEERING APPLIED TO INDUSTRY

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Editor:
WILLIAM E. DICK, B.Sc.

Technical Editor:
J. O. S. MACDONALD,
B.Sc., A.R.I.C., A.M.I.Chem.E.

Assistant Editors:
WILLIAM D. CLIFFORD
G. DILLEY, F.P.S.

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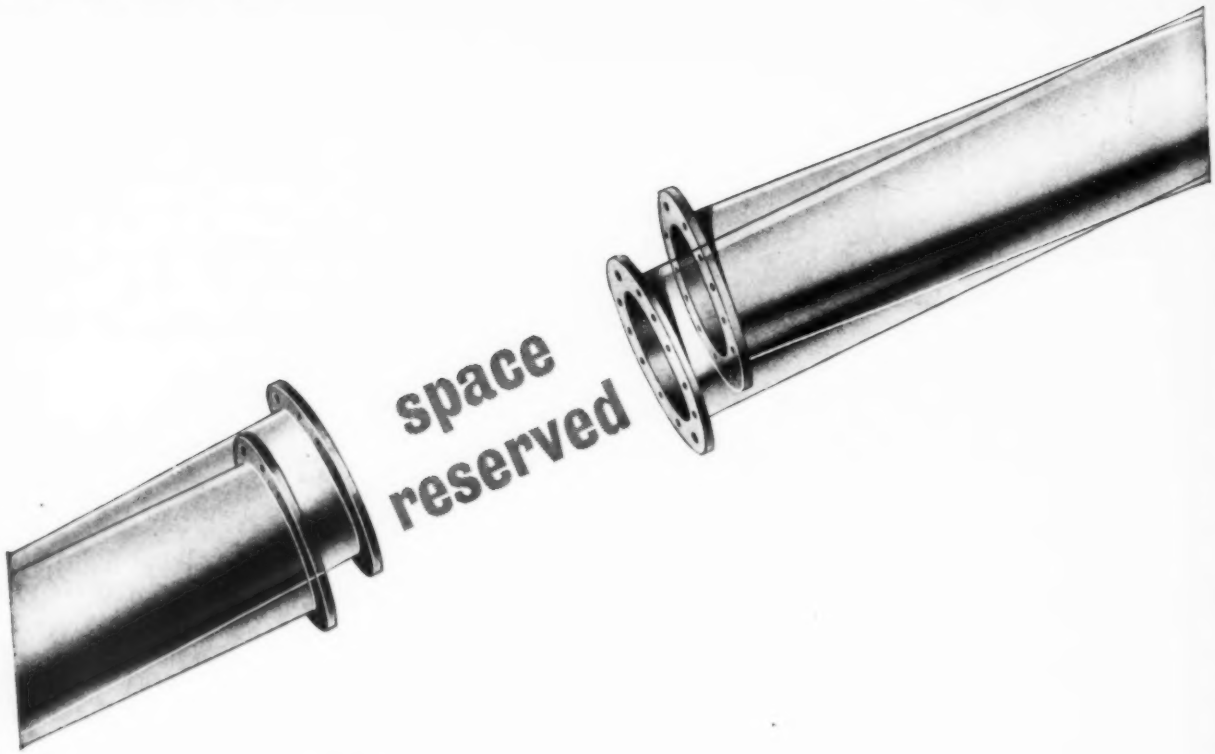

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DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

The Institution's Next President

ON April 30, at the annual meeting of the Institution of Chemical Engineers, Mr. John A. Oriel will hand over the reins of the presidential office to his successor. He is Sir Hugh Beaver, K.B.E., M.Inst.C.E., M.I.Chem.E., M.E.I.C. His name became a household word as a result of his widely praised service as chairman of the Government committee on air pollution, whose report formed the basis of the Clean Air Act.

After a few years spent in India, he became, in 1922, Sir Alexander Gibb's assistant in the newly formed firm of consulting engineers, Sir Alexander Gibb and Partners. He was made a partner in this famous firm of consulting engineers in 1931. Pre-war his particular interest was in developing the industrial engineering side of this concern, and he concerned himself with such matters as factory planning and building, and industrial layout. He was associated with the measures taken to introduce industry into the depressed areas, and he acted as consultant to the Commissioner for Special Areas when the start of the trading estates was being planned. He was later to put the experience he gained in this field to useful purpose when he joined the New Towns Committee responsible for laying down the pattern and principles on which new towns like Crawley and Harlow have been built. During the war he was Director General and Controller General in the Ministry of Works, and his war work gained him a knighthood.

He has served on the Advisory Council of the D.S.I.R., first as a member, and then as chairman (1954-1956). Since 1946 he has been managing director of Arthur Guinness, Son & Co. Ltd. and he is on the board of Richard Thomas & Baldwins Ltd. This March he was elected president of the F.B.I. Like Mr. John Oriel, he devotes a considerable amount of time to work on behalf of the Industrial Fund for the Advancement of Scientific Education in Schools, of which he is chairman.

Mechanisms of Catalysis

A NUMBER of useful papers on catalytic mechanisms were delivered at the Second International Congress of Surface Activity held in London. One by a group of researchers of the Shell Development Company of Emeryville, Calif., dealt with the behaviour of silver, which is a unique catalyst for the oxidation of ethylene to ethylene oxide. An essential part of the catalytic action is the adsorption of oxygen on the silver, and the Emeryville workers gave the results of their investigations into the interaction of oxygen and a silver surface.

Initially the oxygen is adsorbed as molecules; this is a rapid process, that is followed by a slower adsorption requiring many hours for completion. In one set of experiments, it was found that of the total oxygen adsorbed in an hour about 50% was adsorbed in one minute and 80-90% in the first 10 minutes. In the measurable region of their graphs for "fraction of surface covered" against "time" the curve can be fitted to an equation of the type $dq/dt = a \exp(-bq)$, where q is the amount of oxygen adsorbed, t is time, and a and b are constants. Under vacuum the silver surface (at 200°C) lost 30-50% of the adsorbed oxygen rather easily, but thereafter the oxygen was detached at a much slower rate. This effect was not due to loss of the catalyst's surface area. Saturation of the catalyst surface corresponds to a situation where each surface atom of silver holds one oxygen atom. They concluded that the mode of the early adsorption is likely to be related to the reaction mechanism.

Froth Flotation

Froth flotation also came under discussion by the Congress. P. F. Whelan summarised the findings which have emerged from five years' work by the N.C.B.'s Coal Research Establishment, Stoke Orchard, on this process which is exploited to prepare 2 million tons of fine coal annually in Britain. For coal flotation a variety of commercial oils and mixtures of crude cresylic acids and creosote are used, about 1 lb. per ton being needed for high-rank coals and larger amounts for low-rank coals. Whelan's paper provides references to published work on the efficiency of impeller flotation machines and agitation-froth flotation machines. To eliminate the pyrite present in the treated coals, lime is added in controlled amounts, and there needs to be careful adjustment of the quantity of frother.

Cetyl Alcohol and Water Conservation

Two papers were read dealing with the use of cetyl alcohol to reduce evaporation from reservoirs. One described the treatment of a 105-acre reservoir in Tanganyika, where evaporation was cut down by over 30% during a trial lasting four months. Tests indicated that the samples of cetyl alcohol containing the largest proportion of stearyl alcohol are most efficient. I. K. H. McArthur of Price's (Bromborough) Ltd. and K. Durham of Unilever gave results of laboratory trials showing the superiority of commercially available blends of these two alcohols over cetyl alcohol. The rate of spread of the blend is improved by the incorporation of 5-8% oleyl alcohol. The alcohol blend need only be applied over a small area of the reservoir, for favourable winds will rapidly spread the protective film over the remainder. The material can be used in the form of powder or beads. Bead-formation techniques have been investigated, and one promising method that provides beads of uniform size depends upon the application of sonic vibration to a jet of liquid, the drops so formed solidifying into beads on cooling.

New Method for Dewaxing Oils

H. Mondria of the Koninklijke/Shell-Laboratorium, Amsterdam, told the Congress about an unconventional process for dewaxing mineral oils. Instead of filtering the

crystal mass obtained by chilling the oil (usually as a solution in a suitable solvent), the wax is transferred from the chilled solution to an auxiliary aqueous phase with the aid of water-soluble surface-active agents by utilising the phenomenon of wetting reversal. The suspension of wax in the auxiliary phase is separated from the wax-free solution of oil in solvent, and the former is treated with fresh solvent in order to reduce the oil content of the wax. The wax may be recovered from the dispersion by several methods, one of them based on wetting reversal. The process has proved successful in laboratory and pilot-plant trials. In a number of applications it bids fair to be more efficient and/or less costly than the filtration-and-sweating or the selective solvent-filtration processes.

Homogeneous Aqueous Reactor Project

DEVELOPMENT of the homogeneous aqueous reactor as a power-producing unit represents one of the chemical engineer's dreams which promises to pay off comparatively soon. Harwell has made a design study that may well bear fruit as a full-scale working reactor in 10-15 years. A feasible design was described in the paper which Dr. R. Hurst, I. Wells and D. Newby—respectively a chemist, a chemical engineer and a mechanical engineer belonging to Harwell's Homogeneous Aqueous Reactor Project—presented to the Institution of Chemical Engineers on April 2. The reactor design is for a two-zone breeder reactor with an output of 100 megawatts. Its heart consists of a *core* (containing uranyl sulphate in heavy water) surrounded by a *blanket*—which is a circulating slurry of thorium oxide. The thermal load is divided 300 megawatts/100 megawatts between core and blanket. The diameter of the core system is 7 ft.; of the blanket system, 11 ft. (The latter dimension is regarded as the limit for present fabrication techniques for the type of pressure vessel that is required.)

The heat generated in the core solution and in the thorium slurry is tapped to produce saturated steam at 350 psi. Pumping of the slurry requires a "canned rotor" pump specially designed to exclude slurry from the rotor end. An elaborate gas-handling circuit would be needed to handle the deuterium, oxygen and xenon-135 that are produced; the latter fission product is a neutron poison and has to be eliminated from the system.

Corrosion and other Problems

Corrosion of the core vessel presents a serious problem; under radiation even zirconium corrodes, and suppression of its corrosion is not yet in sight. Probably titanium will have to be used for such items as pump impellers. A vital question that arises is pump reliability, and suitable long-running pumps have yet to be proven. The design of pumps (circulating and injection types) to handle the slurry is not far advanced, and the design of heat exchangers for slurry also poses difficult problems. Remote maintenance procedures will have to be worked out for pumps and valves—possibly also for heat exchangers. The policy of going straight to a prototype without a pilot-plant stage, as was possible with the Calder Hall type of reactor, does not seem to be feasible. Probably about five years will be needed before the project emerges from its pilot-plant stage, and another five years may elapse before a prototype could be brought into operation.

Chemical Engineering Vacation Courses

SINCE 1946, nearly 900 university students have attended vacation training courses at Shell oil refineries, chemical plants, research centres and laboratories in the United Kingdom. In the first year only 14 science students were offered facilities under this scheme. Since then the demand has grown steadily, and by 1956 the number of places offered to students had risen to 140. Six-week courses will again be available this year during the long vacation, from July 1 to Aug. 9, and from Aug. 12 to Sept. 20. They are open to students of chemical and mechanical engineering, chemistry, physics, metallurgy and biology.

It is emphasised that these are practical instruction courses, not "holiday relief" posts, and that they have been designed specifically to give students practical experience in the oil industry. The scheme is operated on a residential basis and students taking part are housed together at a local hotel. Accommodation and full board are provided free of charge and the company also covers the cost of travel as well as paying a small sum each week to cover incidental expenses. Some special courses are also arranged, for example, at Thornton Research Centre in Metallurgy and Statistics.

Meniscus Shaft Seals

IN an Institution of Mechanical Engineers' paper on the sealing mechanism of rubber oil-seals, E. T. Jagger concluded that the main sealing agency is the meniscus at the oil-air interface. He showed that the pressure at which leakage occurs is clearly defined, and according to his experiments it is in the region of 18 psi. The absolute figure, however, depends upon the applied load to which the seal is subjected. In a series of experiments in which the oil-air interface was replaced by an oil-liquid one, that variation resulted in an appreciable increase in oil leakage at the seal. This and other evidence had indicated the conclusion that he had adopted.

Canadian v. S. African Uranium

THE past few weeks has brought the release of information about current uranium production in S. Africa (hitherto regarded as an "official secret"), and an indication of how Canadian output will expand following the Canadian-U.K. deal announced on March 29. In 1956 S. Africa produced more uranium than any other country. Its output of uranium oxide totalled 4440 tons, and by the end of 1956 her production rate was equivalent to 5000 tons a year. The equivalent weight of uranium metal she produced last year was 3800 tons. The comparable figures for N. America were: *Canada*, 3300 tons of uranium oxide in concentrates; *U.S.A.* 6000 tons of uranium oxide. It is estimated that communist countries made 3000-4000 tons of metal. Other important producers are Australia, Brazil and the Belgian Congo.

£65 million Spent on Plant

In the near future S. African output of oxide is likely to rise to 5500-6000 tons a year. By 1960 Canadian production is expected to rise to some 16,000 tons per annum. United States production to over 6000 tons and the combined Soviet bloc production to approximately the same figure. Over £56 million has been spent on S. African uranium installations, and an additional £9 million on ancillary sulphuric acid plants. All the impure uranium oxide slurry produced in S. African plants has been refined at the £1,500,000 plant of Calcined Products (Pty) Ltd. near Johannesburg. The average uranium content of

the S. African ores (mainly a by-product of gold mining) is ¼-1 lb. of oxide per ton of ore.

Canada's reserves of uranium ores are put at 225 million tons, with an oxide content of 237,000 tons. (For S. Africa the corresponding figures are 1100 million tons and 370,000 tons.)

Britain's Uranium Requirements

The United States has had a near-monopoly of Canadian uranium under a contract that the U.S. Atomic Energy Commission signed with the Canadian Government agency, Eldorado Mining and Refining. The U.K. Atomic Energy Authority's agreement with that agency covers the supply of £115 million worth of uranium by 1962, when the U.S.-Canadian contract expires. Britain is expected to receive 700-1000 tons of uranium metal a year from Canada during the five-year period. By 1959 Canada should be producing at least 12,500 tons a year—about half the total supply of this primary nuclear fuel to the western world. Approximately four times that quantity will be needed for the nuclear power programmes of Britain, the United States, the Euratom countries and Japan over the next decade. Britain's expanded nuclear programme (see "Digest", April, p. 175) by itself will account for 7000-10,000 tons of uranium metal, this figure being the total for the initial fuel charges for the reactors of the 19 power stations.

Sir Edwin Plowden (chairman of Britain's A.E.A.) has just returned from a S. African tour during which he discussed uranium supplies. On his return he said there is a future for uranium production in Rhodesia.

The Profession of Chemistry

IN his presidential address entitled "The Profession of Chemistry" delivered at the annual meeting of the Royal Institute of Chemistry in London on April 5, Dr. D. W. Kent-Jones said that all would be well with recruitment to the profession if schools knew of the prospects of chemistry as a career. The profession was behind-hand in its publicity work but, recently, the Institute's fund for development of education in chemistry had been established and, during the period of office of Dr. Kent-Jones's successor, the first of a series of books and films would be under way and these would convey to young people an idea of some of the glamour of chemical work. As the fund was a benevolent trust it should attract money from industry and individuals who were interested in the advancement of chemistry, he said. As a promising sign of the times Dr. Kent-Jones pointed to the increasing number of chemists who are occupying positions of authority. There was every reason why scientists as well as arts graduates should hold such appointments, but that meant that more scientists must show that they have breadth of knowledge and vision, an appreciation of commerce and an ability to evaluate situations. He drew attention to the encouraging growth of the Institute which now had about 15,000 members compared with 1000 at the beginning of the century. Records showed that 70% of chemists who were eligible for membership belonged to the Institute. Although this percentage was good it could be improved, and Dr. Kent-Jones appealed to all chemists who were eligible to join the organisation for their own sake, that of the profession and, indeed, for the benefit of the public.

Dr. Kent-Jones has just completed a record period of eleven years as a member of the RIC council.

Chemical Engineering and Industrial Biology

Sir: Your leader, "The Future of Biochemical Engineering", was very timely and I agree entirely that there is a great deal of scope for the extension of chemical engineering into the field of industrial biology. One such extension is the replacement of batch by continuous processes. In the field of inorganic and organic chemicals there is now a good understanding of the principles of continuous reaction and this has facilitated the design of continuous reactors on the basis of laboratory studies of the chemical kinetics. The possibility of carrying out a similar development for brewing, and for fermentation and other biological processes generally, is very attractive.

Of course as soon as one is concerned with micro-organisms there are new problems to be faced. The kinetics of cell reproduction and growth are involved, as well as the chemical kinetics or the reactions. Moreover in any continuous process there is a distribution of residence times, with the result that there is always a fraction of the liquor which has been present in the reaction system for a time much longer than the "mean time of passage". The system is not periodically flushed out and renewed, as it is in a batch process. For this reason mutant strains of the micro-organisms may make their appearance.

Difficulties such as these are a challenge to invention and will surely be overcome. There is already a promising basis for the applied kinetics of biochemical reactions in studies such as those described by Hinshelwood in his *Chemical Kinetics of the Bacterial Cell*.

Yours sincerely,

K. G. Denbigh.

Department of Chemical Technology,
University of Edinburgh.

Biochemical Engineering

WE continue to receive letters about the Leader on "The Future of Biochemical Engineering" which we published in our March 1957 issue (p. 121). One of them—from Prof. Denbigh of Edinburgh University—we print *in extenso*. Another letter comes from Dr. H. W. Melville, head of the DSIR; in this he refers to the Chemical Research Laboratory's "considerable interest in microbiology," and the final sentence of his letter reads as follows: "At the moment we are surveying all our Stations' programmes; this will take some time, and microbiology will figure in our discussions though it is difficult at the moment to determine what is the most appropriate course of action."

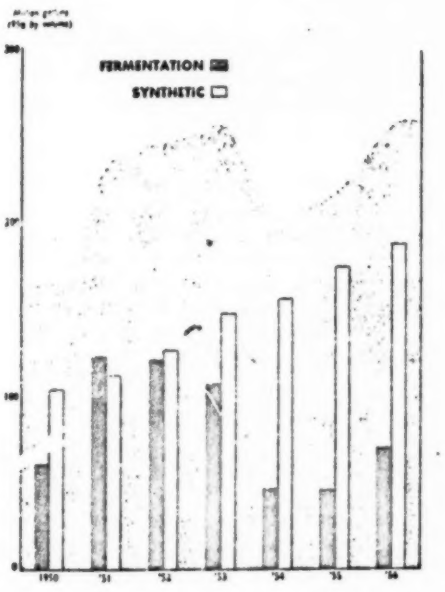
Acetone and Holton Heath

Since the appearance of our Leader on this subject, *Chemistry and Industry* (March 9, p. 274) has printed an important paper by J. J. H. Hastings of Distillers Co. (Biochemicals) Ltd. dealing with "New Products of the Fermentation Industry". In this he refers to the fact that Prof. Kennedy Walker (who is still hard at work at the Manchester College of Technology) was a pioneer with Weizmann of the acetone/butanol fermentation in World

War I. After laboratory work at Manchester, this process was developed in a pilot at Nicholson's brewery in London, and then exploited in a full-scale plant which was built at the Navy's cordite factory at Holton Heath. (As part of the Navy's recently announced economy drive, the Holton Heath establishment is due for early closure). Mr. Hastings points out that it was not until 1935 that this fermentation (by now based on molasses) was commercially established in Britain at the butanol factory which Commercial Solvents Corporation erected at Bromborough. His paper stresses the ever-increasing competition between biochemical processes and petrochemical plants, though the latter brings about a depletion of non-replaceable reserves whereas "fermentation processes are the natural corollary of the harvests that man gathers year by year in perpetuity."

Petrochemical v. Fermentation Processes

Syntheses from petroleum have already disturbed the production of the following chemicals by fermentation: ethanol, acetone and acetic acid. In the United States the trend has been for petrochemical ethanol to overwhelm fermentation alcohol, as the accompanying graph shows. The trend has gone so far that many fermentation producers have gone out of business, with the result that a serious gap between ethanol demand and supply has arisen. This trend is a measure of the pressure which the petroleum lobbyists can exert. The farm group is now hitting back, and is backing the proposal of Publicker Industries for the chemurgic processing of vast quantities of corn. The U.S. President recently appointed a Bipartisan Commission on Increased Use of Agricultural Products, and this advocates the utilisation of surplus corn—to the tune of 100 million bushels a year—in ten fermentation alcohol plants and two Government plants that would make butadiene from alcohol; 30 million bushels could be used instead of blackstrap molasses for ethanol manufacture, and the remaining 70 million would go into butadiene production.



The graph shows the competition between synthetic (petrochemical) alcohol and fermentation alcohol in the U.S.A.

Developments in Rubber Technology

A CHALLENGE to both the natural grower and the synthetic rubber producer, with great opportunities for both, is presented by the growing demand for rubber, declared Mr. G. E. Beharrell, managing director of Dunlop, when opening a symposium on synthetic rubber organised by Rubber and Plastics Age in London recently. Last year more than 3 million tons of rubber were used throughout the world, of which 40% was synthetic, he said. Assuming that the demand for rubber kept pace with the normal trend of economic development the consumption of rubber from both sources within the next ten years could be assessed at more than 4 million tons annually.

In the course of the symposium Professor P. Baumann, of Hüls A.G., said that a new synthetic rubber plant to be erected in Western Germany would produce 45,000 tons a year of Buna Hüls K rubber. This was a cold rubber—a butadiene styrene copolymer produced at 41°C with a Redox system for the catalysis. The dehydrogenation of n-butane to butadiene will be made by the Houdry process, and the dilute butadiene so obtained will be concentrated by the Esso copper-ammonia acetate extraction process. 38,000 tons of butadiene will be manufactured yearly and 6000 tons will be available for purposes apart from rubber manufacture. Styrene will be supplied to the plant by Hüls Chemische Werke. Mr. R. P. Kenney of Goodrich Co. stated that the economic future of Ameripol SN, a cis-1,4-polyisoprene rubber, depended on the price of isoprene. At the moment that did not allow of a great production of the rubber but he thought that the cost of the starting material would fall. An economic price would be about that of butadiene. The rubber was being made in America on "a large pilot plant or small production plant" in quantities of 60,000 to 100,000 lb. a month and was being used for modification experiments.

B.O.C. Answers Monopoly Commission

BRITISH Oxygen has produced a booklet giving its considered reply to the Monopoly Commission's report, the main points of which we summarised in "Digest" (Feb. 1957, p. 57). To the Commission's comment that B.O.C. should not try to control the provision of plant to other suppliers, or consumers who might wish to make their own oxygen, the company says that the increased use of tonnage oxygen (a 400% increase in ten years) has led B.O.C. to reconsider the economics of privately-owned oxygen plants. It states that "no difficulty is placed by B.O.C. in the way of any customer who wishes to purchase plant from B.O.C. or from any competitor."

B.O.C. now agrees the principle of the Commission's point that the company should refrain from using "fighting companies" and has already applied it in practice. The company also accepts the Commission's recommendation that a consumer ought not to be restricted in his gas purchases by terms attached to apparatus.

Correction

A MISPRINT occurred in our March 1957 issue, in Dr. O. B. Volckman's article ("The Practical Application of Electrodialysis for the Desalting of Brackish Water.") The design capacity of the full-scale plant planned by S. African mining companies (p. 148) is 100,000 gph—*not* 1000 gph, as printed. Dr. Volckman tells us that, as a result of further developments on the Welkom pilot plant, the initial requirements for the proposed 100,000 gph plant can be met by a reduced number of membranes; 8000 anionic and 8000 cationic membranes are now involved.

BRITISH CHEMICAL ENGINEERING
A HEYWOOD TECHNICAL PUBLICATION

The Institution's Royal Charter

IN the very first Leader which we published, we spoke of the wide appreciation that now exists in Britain of the vital importance of chemical engineering, the fourth primary technology which ranks alongside civil, mechanical and electrical engineering. We expressed the hope that this point would soon be given official recognition by the granting of a Royal Charter to the Institution of Chemical Engineers. A petition to the Queen for a charter was submitted by the Institution above the following signatures: John A. Oriel, Sir Harold Hartley, P. K. Standring, F. A. Greene, F. E. Warner, Sir Hugh Beaver, Sir Alexander Fleck, Sir Christopher Hinton and Sir Ewart Smith. The Queen has now approved the granting of a charter. The Institution of Chemical Engineers is thus raised to the same status as the great institutions which represent the professions of civil, mechanical and electrical engineering. The event represents official recognition of the highest order of the importance of the chemical engineering profession.

Noteworthy is the fact that the Institution of Chemical Engineers has gained its charter relatively soon after its foundation. The Institution of Mechanical Engineers had to wait no less than eighty-three years before it received its charter; again, the Institution of Electrical Engineers was founded in 1871, but did not receive its charter until 1921. What is clear from the fact that the Institution of Chemical Engineers has received what may fairly be described as preferential treatment over its application for a charter is that the three old-established and chartered institutions supported the idea that the chemical engineers should be raised to the same status as themselves. It is a most encouraging sign of the times that this should have happened, and a token of the strength of the bonds that link the institutions covering the four primary technologies to the mutual benefit of all their members.

Approval of the petition must give great pleasure to all members of the Institution of Chemical Engineers. On this occasion, the thoughts of its older members are bound to go back to those great campaigners who fought the cause of chemical engineering in Britain and who made industry realise the full value of the chemical engineer's approach to production problems. The pioneers like George E. Davis, J. W. Hinchley and Hugh Griffiths, who gave chemical engineering education its start here; men like Lord Moulton, who gave chemical engineers such as K. B. Quinan the chance to demonstrate what could be achieved by the application of chemical engineering methods to the vastly expanded manufacture of explosives in World War I; men like Seligman, Reavell and Rambush, who showed how the new methods could revolutionise plant design. Chemical engineering was slow gaining ground in the early days, and, indeed, the pioneers had to fight down some ill-conceived prejudices that industrialists held against chemical engineers, prejudices which slowed down the development of this all-important technology in Britain. The reluctance on the part of industry to make the most of chemical engineers had the effect of delaying the start of university courses of chemical engineering. As Prof. J. M. Coulson said at this month's Birmingham conference on chemical engineering education, we have only had serious courses in Britain for some twenty years, and it is only since 1945 that there have been any appreciable undergraduate courses. Since 1945 the climate of industrial opinion has altered out of all recognition, and today industrialists are saying that the annual output of chemical engineers ought to be five times bigger than it is at present. In response to this demand, chemical engineering training facilities have expanded enormously. No less than twenty colleges in Britain now offer courses in chemical engineering. Pre-war, there was only one university chair in chemical engineering; now there are nine—at Birmingham, Cambridge, Durham, Edinburgh, Glasgow, Manchester and Swansea, with two in London—at Imperial College and University College. In addition, departments that include chemical engineering exist also in the universities of Leeds and Sheffield.

Today the number of chemical engineering degrees awarded annually exceeds 300, and a big increase over that figure can be expected now that new university departments have been created. When the Institution of Chemical Engineers was founded in 1922, not one British university offered a course in the subject—by contrast, the number of students studying chemical engineering in U.S. universities was then around 6000. As no degree courses existed, the Institution was forced at the outset to organise its own qualifying examination, which nowadays is recognised all over the world. The qualifying activities of the Institution are still of first importance, though the task of examining students has been lightened by the growth of courses in chemical engineering in the universities and colleges of technology.

The Institution has been growing steadily in size; in the past twenty years the membership has risen from 880 to 3500. Its influence extends far beyond these shores, while in Britain it is influential far beyond engineering and industrial circles. No engineering institution has better "public relations"; it maintains, for example, effective contact with the schools, and one can be sure that the chemical engineering profession will not lack recruits. Its activities benefit the country as a whole, and no Royal Charter can have been more well deserved.

SASOL:

WORLD'S LARGEST OIL-FROM-COAL PLANT

by J. C. HOOGENDOORN and
J. M. SALOMON, B.Sc. (Eng.), Ph.D.

SASOL will produce about 20% of South Africa's petroleum requirements from high-ash bituminous coal. This integrated factory, which works two variants of the Fischer-Tropsch process, will also make a range of some twenty chemicals. The gas production processes involved in the plant, including that of purification, are described in this article

THAT every modern country needs a reliable source of petroleum has been amply illustrated by the recent events in the Middle East. Although South Africa is richly endowed with most minerals, in particular an abundant supply of coal of poor quality with a high ash content, no deposits of natural petroleum have been found and all indications are that no substantial oil-fields exist in the Union. It is to remedy this serious deficiency that Sasol has been established.

SASOL derives its name from the initial letters of the Afrikaans title of the operating organisation—Suid-Afrikaanse Steekool-, Olie- en Gaskorporasie (S.A. Oil, Coal and Gas Corporation). The Sasol project is a pioneering venture in the field of hydrocarbon and chemical synthesis. In the years before the Second World War several Fischer-Tropsch factories were completed in various countries; by 1938 nine factories were operating in Germany, one in France and one in Manchuria. Sasol, however, is the largest factory so far built, and the only one expected to be economically successful.

Five offers were received for the design and erection of the factory in 1951, and after thorough examination it was clear that important economic and technical advantages would result if processes submitted by the M. W. Kellogg Co. of America and Germany's Arge—Arbeit-Gemeinschaft Lurgi und Ruhrchemie—were combined into an integrated project. In addition to these main contractors, various units and items of equipment were supplied by firms from six other countries. Overall control of the construction was maintained by M. W. Kellogg Co. The ultra-modern, highly instrumented factory is situated on the banks of the Vaal River in the north-eastern Orange Free State above an extensive deposit of low-grade coal.

The coal is mined by the pillar-and-stall method, which obviates the need for propping of the roof. Three seams (respectively 11 ft, 24 ft and 10 ft thick) at depths ranging up to 500 ft below the surface comprise the deposit, which has been estimated at 665 million tons. Of this, more than 300 million tons are extractable. The main haulage shaft is inclined at 18 degrees to the horizontal. The coal, which is mined by the most modern mechanical methods, is brought to the surface by a conveyor belt, 4 ft wide and 1450 ft long, which is quite adequate for handling the 8000 tons/day mined. The coal is crushed to a suitable size and belt-conveyed $1\frac{1}{4}$ miles to the factory storage bunker, which has a capacity of 31,000 tons and is blanketed with nitrogen to prevent spontaneous combustion. Again by conveyor belt, the coal is transported to a sizing shed where it is separated into pieces up to $\frac{3}{8}$-in. square mesh and $\frac{3}{8}-1\frac{1}{2}$-in. square mesh. The former are used for firing the pulverised-fuel boilers which are used for raising steam. The capacity of the power house, where three of the four boilers are usually in operation, is 1,000,000 lb/hr of steam at 500 psig and 750°F. Part of this steam is used for driving the turbo-alternators, and the rest is used as process steam.

The larger pieces of coal are gasified under pressure in the Lurgi pressure gasifiers, using steam and oxygen under pressure. The cost of the coal delivered to the bunker is in the region of 5s. 6d. per ton.* The oxygen is prepared in a Linde oxygen plant, the largest in the world, which has a capacity of 2000 tons/day of 99% oxygen.

Fig. 3 shows the integrated nature of the project and the wide range of products that can be produced.

Unique "Rectisol" Plant

The gas from the gasifiers is purified in the unique "Rectisol" plant, in which it is contacted with cold methanol under pressure. This process removes all the H_2S and organic sulphur, and 98% of the CO_2 from the gas. After purification, the gas is either passed through the German fixed catalyst-bed synthesis reactors, or to the gas re-forming section where the methane is converted to CO and H_2 and thence to the Kellogg circulating catalyst reactors. The "tail" gas from the German reactors is also re-formed and added to the fresh feed to the American synthesis section.

Hydrocarbon products from the two different synthesis

* All tons are 2000 lb.

units are separated in petroleum refinery units, specially adapted to handle the Fischer-Tropsch product range. The water-soluble oxygenated compounds from the two synthesis plants are treated together; the unsaturated gases (predominantly propylene and butylenes) from these two units are treated together in a polymerisation unit and converted into high-grade gasolene.

An interesting feature is the fact that, although the recovery of ammonia and tar acids from the aqueous effluent is essential before this can be discharged into the Vaal, this recovery is so organised that an erstwhile nuisance has been turned into a source of revenue.

The factory may conveniently be divided into the following sections: (i) gas preparation; (ii) synthesis; (iii) product recovery; and (iv) ancillary plants and utilities.

Gas Preparation

This section will be discussed under the following four headings:

(1) Oxygen production
(2) Gasification
(3) Gas purification
(4) Gas re-forming

(1) *Oxygen Plant.* Although the first industrial approach to the liquefaction of air was made by Dr. Carl von Linde in 1893, it was only in 1902 that rectification of the liquefied air was employed. In 1910 Linde developed the double column, which has remained in vogue until today. The development by Claude of a new method of cold production—the expansion of high-pressure air in an engine, which gives far better cold production per pound of air than does the Joule-Thomson effect—was another step forward. When Fränkl, in 1925, suggested regenerators as heat exchangers, discovering during their demonstration that the effluent gases "cleaned up" the frozen CO_2 and water from the regenerators, the era of cheap "tonnage oxygen" began. All these features are incorporated in the Sasol oxygen plant (see Fig. 2).

The Sasol oxygen plant consists of six Linde units, of which five are normally in operation and one on standby. Each unit processes 1,840,000 scfh of air at a pressure of 71.5 psia to produce 347,000 scfh of oxygen gas of 99.1% purity, 675,000 scfh of nitrogen containing 0.03% oxygen, and 675,000 scfh of nitrogen containing 2.6% oxygen. The oxygen recovery as product is 94.4% of the oxygen fed.

Each unit has a turbo-compressor for the inlet air. The air at 71.5 psia passes through the aluminium-foil-packed regenerative heat exchangers. These regenerators are in pairs, one pair for each product mentioned above. One of the pair passes air, while the other passes cold product; switching is pneumatically done on a time cycle.

The main stream from the regenerators passes to the first pressure column. A small stream is taken off the regenerators through carbon dioxide absorbers and expanded to 5 psig isentropically, realising a large temperature drop to make up for the "cold losses" and producing some electrical power. This expanded cold air is passed into the atmospheric column. The air that enters the column is largely at its dew-point and ascends through the perforated plates. The liquid oxygen, which arises as a bottom product of the atmospheric column, is pumped from the sump and used as a cooling medium in the condensers of the two pressure columns, where it evaporates outside the condenser tubes.

The top product of the atmospheric column is pure nitrogen, whereas the side stream drawn off is impure nitrogen. The oxygen-rich liquid from the sump of the first pressure column is passed over a silica gel filter to the atmospheric column. The silica gel removes the acetylene present, so preventing any dangerous accumulation of this substance.

The three product streams—*pure nitrogen* from the top of the atmospheric column, *impure nitrogen* from the side stream and *pure oxygen gas* from the pressure tower condensers—leave the unit through the regenerators. The working of the oxygen plant may be easily followed in Fig. 2.

The oxygen and nitrogen become available at a pressure of a few inches of water. The oxygen is compressed in a multi-stage centrifugal compressor to 440 psig. This compressor is fitted with elaborate safety devices to prevent any possible accident. Some of the pure nitrogen is compressed for use in the plant as inert gas.

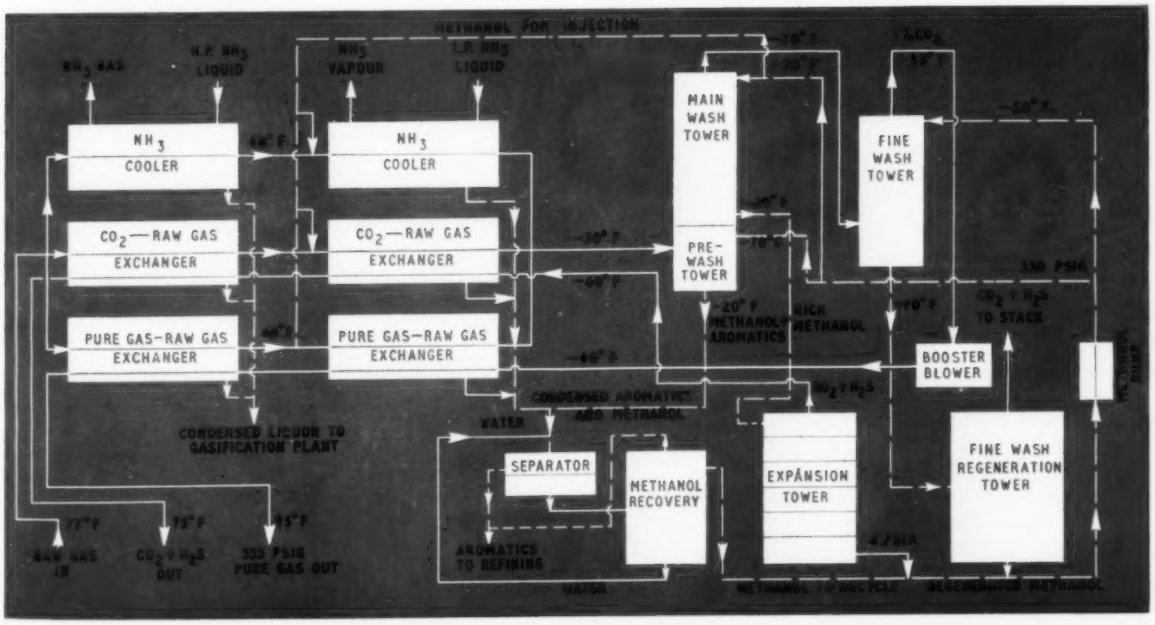


Fig. 1. Block flowsheet of "Rectisol" plant, consisting of three identical scrubbing units followed by a common regeneration section.

The theoretical power consumption for the separation process is the sum of the power required to raise the constituents from their partial pressures to the original total pressure. This works out at 2 kWh per 1000 scf.

The steam consumption of the steam-turbine-driven turbo-compressors is 37,000 lb/hr to supply 1,840,000 scfh. This represents an energy consumption of 42 kWh 1000 scft of 99.1% oxygen produced. This is 20 times the theoretical requirement. The energy recovered is extremely small compared with that used, i.e., about 80 kW compared with 15,100 kW used in the turbine. The largest inefficiency is in the steam turbine; if this is disregarded and the comparison based on the energy input to the air compressor alone, the energy requirements per 1000 cu. ft of oxygen is 7.2 kWh, or 3.6 times the theoretical quantity required.

At Sasol provision is made for the withdrawal of a small amount of liquid oxygen for sale.

Gasification System

(2) *Gasification.* The gasification plant at Sasol utilises the Lurgi high-pressure gasification system developed in Germany during the 1930s (see Fig. 4). Basically, the gasifier (of which there are nine in all) consists of a fixed-bed pressure generator using lump fuel—coal of $\frac{1}{8}$-$1\frac{1}{2}$ in. mesh—which is fed in semi-continuously at the top of the generator, while the ash is semi-continuously removed from the bottom. A steam/oxygen mixture is introduced in the lower part of the generator, the proportions of mixture being so regulated as to provide the desired composition of gas and to keep the temperature low enough to prevent fusion of the ash and formation of clinker. The hot gases rising through the fuel-bed heat the descending coal so that the volatile constituents of the coal are distilled off in the upper part of the vessel.

Increase in pressure favours the formation of the multi-atomic gases CO_2, CH_4 and H_2O, while increase in temperature favours the formation of H_2 and CO. The following are the main reactions that take place in the gasifier: the symbols all represent lb. moles:

$C + O_2 = CO_2 + 169.2$ Btu
$C + CO_2 = 2\,CO - 74.2$ Btu
$2C + O_2 = 2\,CO + 95.1$ Btu
$C + H_2O = CO + H_2 - 56.4$ Btu (above 1000°C)
$C + H_2O = CO_2 + 2\,H_2 - 38.75$ Btu (below 900°C)
$2\,CO + 2\,H_2 = CH_4 + CO_2 + 106.2$ Btu
$CO + 3\,H_2 = CH_4 + H_2O + 106.85$ Btu
$CO_2 + 4\,H_2 = CH_4 + 2\,H_2O + 70.9$ Btu
$C + 2\,H_2 = CH_4 + 32.3$ Btu

Most of these reactions are strongly exothermic and, in order to remove the heat liberated, the gasifier is provided with a water jacket in which a part of the gasification steam is produced; the internals of the gasifier are also water-cooled (see Fig. 4).

The high-pressure process of gasification has the following advantages:

(1) Decreased size of plant for a given output of gas. This is partly offset by increase in capital cost.

(2) Removal of CO_2 and H_2S is facilitated.

(3) Subsequent transmission of the gas is easier.

Its disadvantages are:

(1) Decreased efficiency of steam conversion with consequent increase in consumption.

(2) For synthesis gas purposes, the formation of methane is undesirable. This can be overcome by subsequent re-forming of the methane with the aid of steam and oxygen.

Fig. 4 shows a typical Sasol gasifier with its auxiliary

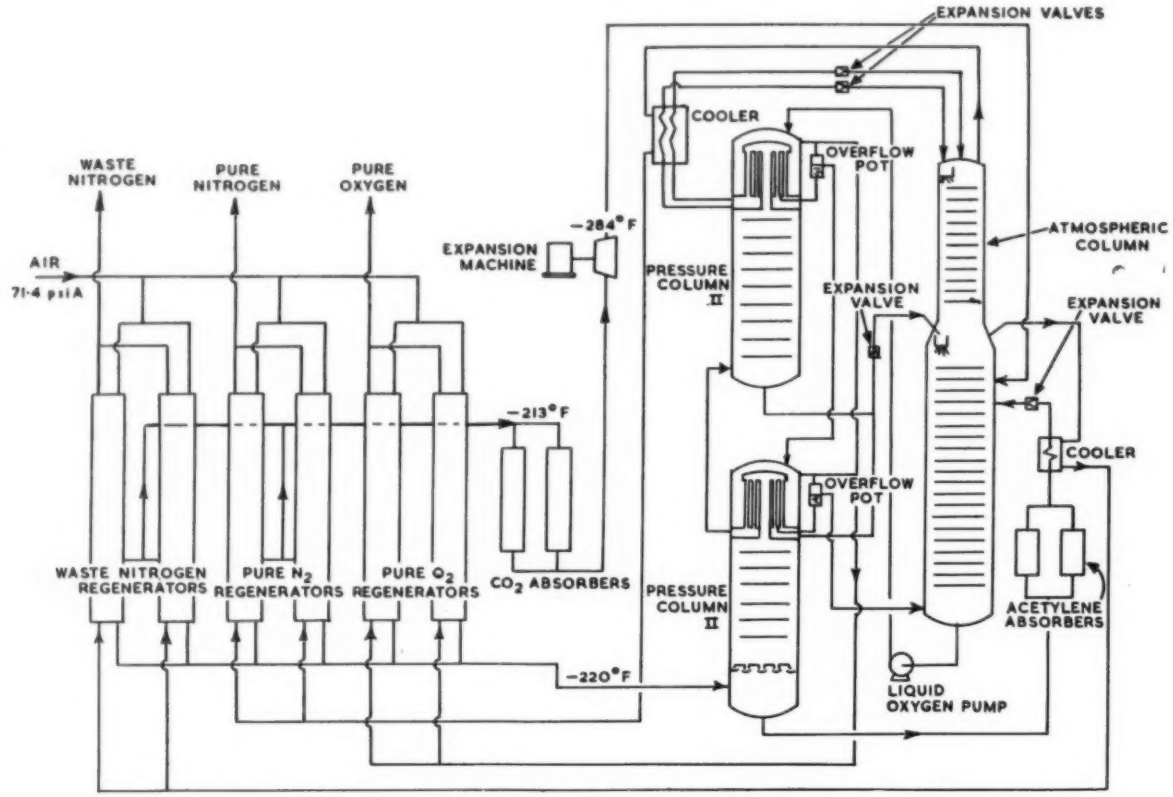


Fig. 2. Sasol oxygen plant consisting of six Linde units, of which five are normally in operation and one on standby. Each unit has a turbo-compressor for the inlet air.

equipment. Each gasifier comprises the equipment shown; only after the pre-cooler are the gases combined into common gas mains. The Sasol gasifier units are the largest yet built and are specially designed to operate with a coal containing normally 28-30% ash. This ash has, fortunately, a comparatively high softening point (1260°C) and clinkering is not a serious problem.

The coal is fed from a hopper into a coal lock which has a capacity of about 6½ tons; the filling cycle takes 7-8 minutes. The lock is then pressurised by gas from the gasifier and the coal is fed on to a rotating distributor in the gasifier. When the lock is empty it is depressurised—the gas being led to a gasholder—and refilled.

The grate and coal distributor are mounted on a common vertical hollow shaft, which is water-cooled and runs from top to bottom of the gasifier. Steam produced in the jacket is led to the mixing vessel, where it is mixed with H.P. superheated steam and oxygen. This mixture enters the bottom of the gasifier through three pipes and is distributed into the fuel bed between the grate sections at three circumferences.

The ash lock is pressurised with H.P. superheated steam and the ash is then discharged from the gasifier. Pressure is released, passing the steam into water in an expansion vessel. The ash then falls into a hopper, from which it is removed by a hydraulic sluicing system. The ash lock is provided with an inner refractory lining.

The gas outlet is provided with a hydraulically-driven scraper to keep it clear. The gas then enters the washer-scrubber, where it is scrubbed with circulating tar and liquor. Due to difficulties with this system in the past, the circulating liquid is now substantially tar free. In the scrubber the gas is saturated, washed free from dust and cooled. It then passes to the waste-heat boiler, where steam at 35 psig is produced. This steam is superheated in a gas-fired superheater using the gas expanded from the coal locks, and fed into the factory L.P. steam network.

From the waste-heat boiler the gas passes through a tube-in-shell pre-cooler, through a pressure control valve, by means of which the gasification pressure is controlled, to one of two common gas mains or—in starting up—to a local flare.

The tar and liquor used in the washer-scrubber condense out from the gas in the waste-heat boiler and pre-cooler. Further condensation takes place in after-coolers, where the gas temperature is reduced to 70-80°F. Water spray removes the final traces of ammonia.

The gas ratio H_2/CO can be adjusted by control of the steam/oxygen ratios. For the high H_2/CO ratio required for the Kellogg synthesis, "cold operation" is used: i.e., a high steam/oxygen ratio is used. For the low H_2/CO ratio required for the Arge synthesis, "hot operation" is required: i.e., a high oxygen/steam ratio is used. In order to keep the temperature down during "hot operation", CO_2 is recycled to the gasifier, and this permits of the use of less oxygen due to the occurrence of the reaction:

$$C+CO_2=2\,CO.$$

Typical gas analyses for different H_2/CO ratios are given in Table 1.

TABLE 1

	Unpurified gas			Purified gas		
CO_2+H_2S ...	28.2	30.2	32.5	0.8	0.9	0.9
O_2	0.0	0.0	0.0	0.0	0.0	0.0
CO ...	22.4	19.8	16.4	31.5	28.5	24.8
H_2	38.0	38.6	29.4	53.6	55.6	59.5
CH_4 ...	10.9	11.0	11.3	13.3	14.2	14.0
N_2	0.5	0.4	0.4	0.8	0.8	0.8
H_2/CO ratio	—	—	—	1.7	1.95	2.4

Approximately twice as much of the "low ratio" gas as the "higher ratio" gas is made. This is in spite of the fact that the Kellogg synthesis consumes almost twice as much gas as does the Arge synthesis. The Arge synthesis tail gas (equal to 50% of the total feed) is re-formed in the gas re-forming unit and added to the feed to the Kellogg synthesis.

TABLE 2

Consumption/gasifier/24 hours	
Coal	470 tons
Oxygen	3,041,000 scft
H.P. steam	793,000 lb.
H.P. feed-water	24,680 gal.
L.P. feed-water	73,850 gal.
Cooling water	1,878,000 gal.
	Grate loading=340 lb./sq. ft/hr.
Production/gasifier/24 hours	
Raw gas	21,620,000 scft
Tar	1352 gal.
Oil	237 gal.
Gas liquor	150,900 gal. (about 1.5% NH_3)
L.P. steam	729,600 lb.
Purified gas	14,078,000 scft
	(Gal.=Imperial gallons; ton=2000 lb.)

(3) *Gas Purification: The "Rectisol" Process.* This process is based on the fact that carbon dioxide and hydrogen sulphide are highly soluble under pressure in cold methanol and are readily released from solution when the pressure is reduced. This pressure reduction is accompanied by a temperature drop, partly due to the Joule-Thomson effect but mainly due to the heat of desorption of gas. This temperature drop, together with efficient heat-transfer apparatus, enables the plant to operate without hardly any external cooling or heating. A small amount of ammonia cooling (mainly to remove the heat of absorption of gas), steam heating and water cooling is all that is required.

The gas leaving the gasification plant contains a large amount of CO_2 and smaller but nonetheless objectionable quantities of H_2S, organic sulphur compounds and aromatic hydrocarbons distilled from the coal in the upper part of the gas generator. In addition, a quantity of fine fly ash is carried over with the gas.

As shown in Fig. 1, the "Rectisol" plant consists of three identical scrubbing units followed by a common regeneration section. Only one scrubbing unit will be described. As already mentioned, the gas required for the Arge synthesis is of different composition from that required for the Kellogg reactors. The gases are kept separate, and either one or two scrubbing units can be used for either Arge or Kellogg gas, depending on the quantities required in each section. *Normally the quantity of "Rectisol" gas required for the Arge synthesis is twice that required for the Kellogg synthesis.* Half of the gas fed to the Arge synthesis is fed as Arge tail gas to the gas re-forming unit where it joins the fresh "Rectisol" gas feed to the Kellogg synthesis. Each unit has a capacity of about 60,000 Nm^3/hr of raw gas or about 42,000 Nm^3/hr of pure gas. (1 Nm^3/hr =37.97 scft measured at 60°F, 14.7 psia and saturated.)

In order to remove the fly ash and any condensate, the gas is first passed through a set of gas cyclones. There is sufficient condensate to ensure complete removal of dust from the gas. For each unit the "raw" gas is then split into three streams for the first stage of the cooling-down process. One stream is cooled by evaporation of high-pressure ammonia, the second by exchange with cold H_2S and CO_2 which have been removed from the "raw" gas, and the third by exchange with cold "pure" gas from which the H_2S and CO_2 has been removed. The three streams, which are at a temperature of about 40°F, are

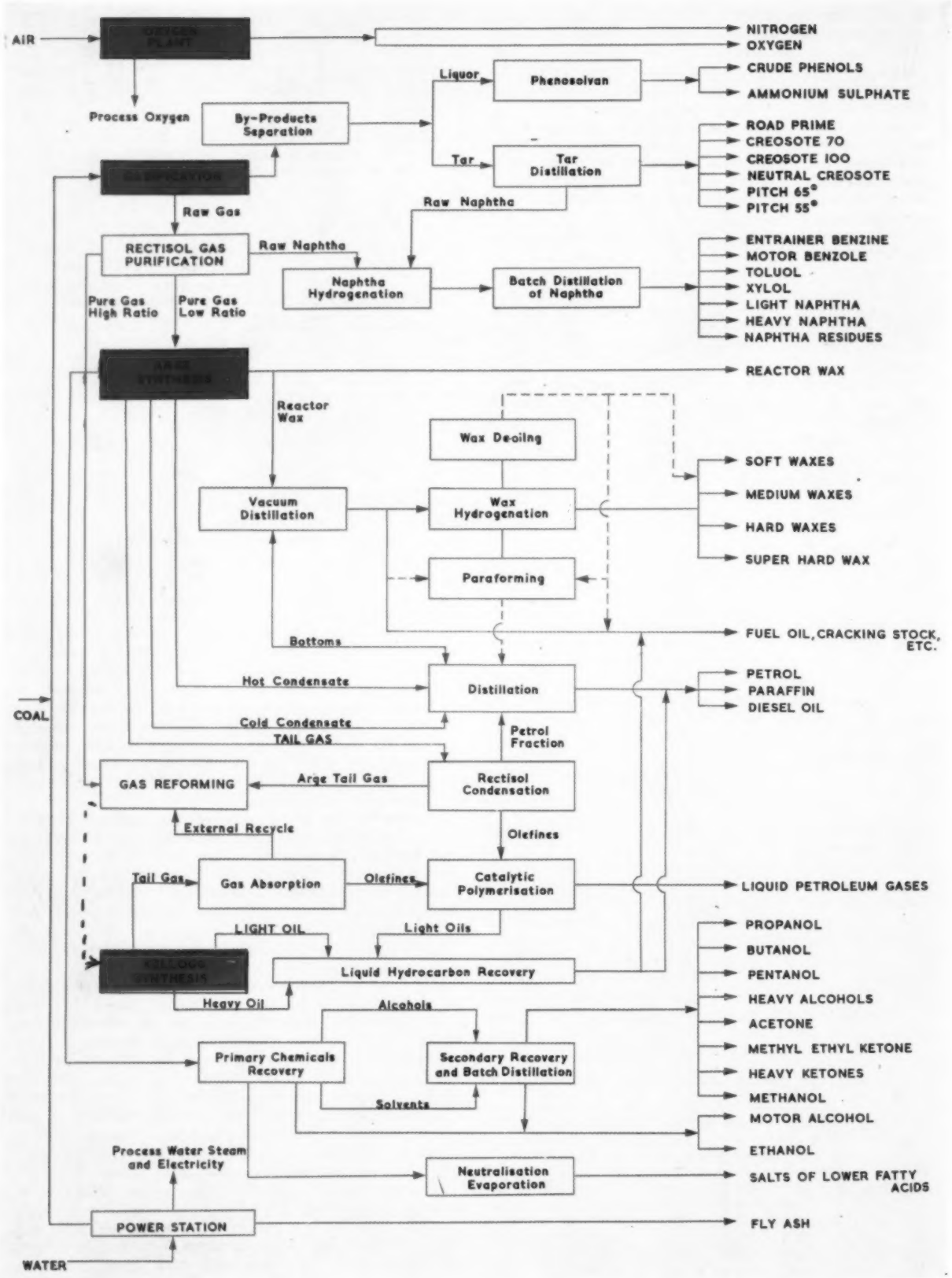


Fig 3. Range of Sasol Products.

then recombined and any condensate (mainly water, with some hydrocarbons) is drained off.

The gas is again split into three streams, methanol injected to prevent any water vapour present from freezing, and the gas cooled further. One stream is cooled by evaporation of low-pressure ammonia, the second by exchange with cold CO_2+H_2S, and the third by exchange with cold pure gas. The cold "raw" gas streams, which are at a temperature of about $-30°F$, are recombined, and the condensate (consisting of methanol, aromatics, organic sulphur compounds and some water) is drained off. (The subsequent treatment of this condensate will be described in a later article.)

Scrubbing Process

The scrubbing process takes place in three stages—pre-wash, main wash and fine wash. The pre-wash and main wash are performed in two sections—one above the other—of a double tower, and the fine wash is done in a separate, smaller tower. The main purpose of the pre-wash stage is to remove the last traces of aromatics and organic sulphur compounds. The methanol used in this stage is at $-70°F$ when it enters the tower and about $-20°F$ when it leaves. The condensate from the second-stage coolers joins the "rich" methanol stream from the bottom of the pre-wash tower. The regeneration of this will be described later.

Most of the CO_2 and practically all the H_2S is removed in the main wash tower. Here, again, methanol of about $-70°F$ is sprayed in at the top of the tower and leaves at $-20°F$. Low-pressure ammonia is evaporated in cooling coils in this tower to remove the heat of absorption of the gas and keep the temperature at the required level. The methanol from this tower is regenerated by six-stage expansion down to sub-atmospheric pressure.

In starting up the plant, the required low temperatures are obtained by circulating methanol at 350 psig through the main wash tower, where it is cooled by the ammonia coils. The cool high-pressure methanol is then expanded to a low pressure, thus obtaining even lower temperatures. This process is continued until the methanol is cold enough for the admission of gas. Gas heat exchange then assists in the process of cooling down. The period required for cooling down is in excess of 24 hours.

The gas leaving the main wash tower passes, at a temperature of about $-70°F$, to the fine wash tower. Here the gas is contacted with methanol at $-50°F$, and the CO_2 content of the gas is reduced to about 1%. The H_2S left in the gas cannot usually be detected.

The cold pure gas is boosted in pressure in a turbo-blower, and after heat exchange with incoming gas it passes—at about 75°F and 335 psig—to the gas main leading either to the Arge or Kellogg units. Gas streams from the other two scrubbing units join the appropriate main at this point.

Regeneration of the "rich" methanol from the second cooler group and the pre-wash tower is brought about in five stages:

(1) the pressure is released in an expansion drum to liberate the absorbed gas;

(2) water is added to the rich methanol, bringing about a separation between the watery methanol and the naphtha, as the aromatics-organic sulphur mixture is called;

(3) the naphtha is removed from the watery methanol and pumped to another section of the factory;

(4) the watery methanol is stripped to remove last traces of the naphtha; and

(5) the watery methanol is rectified in a second distillation column. The overheads, practically pure methanol, are cooled by cooling water and then pumped to the main wash expansion tower.

The methanol from the main wash tower is expanded in six stages in one of two expansion towers to a pressure of about 4 psia. The expansion gas from the two sub-atmospheric stages is boosted in pressure by two-stage compressors before being discharged to atmosphere. The gas from the other four stages, containing about 98.5% CO_2 and 1.5% H_2S, is used for cooling incoming raw gas before being discharged to atmosphere.

Regeneration of the fine wash methanol is partly achieved by expansion in a drum to liberate absorbed gas. This is completed by distillation to remove the last traces of CO_2 and H_2S. To prevent methanol loss, the overhead gases are led to one of the two expansion towers. The regenerated methanol from the three towers is continuously pumped at the required pressure and temperature back into the towers.

The fact that the outgoing pure gas and CO_2+H_2S are within 2°F of the temperature of the incoming raw gas speaks a lot for the design of the heat-exchange equipment.

Besides its absolute freedom from H_2S and the very low

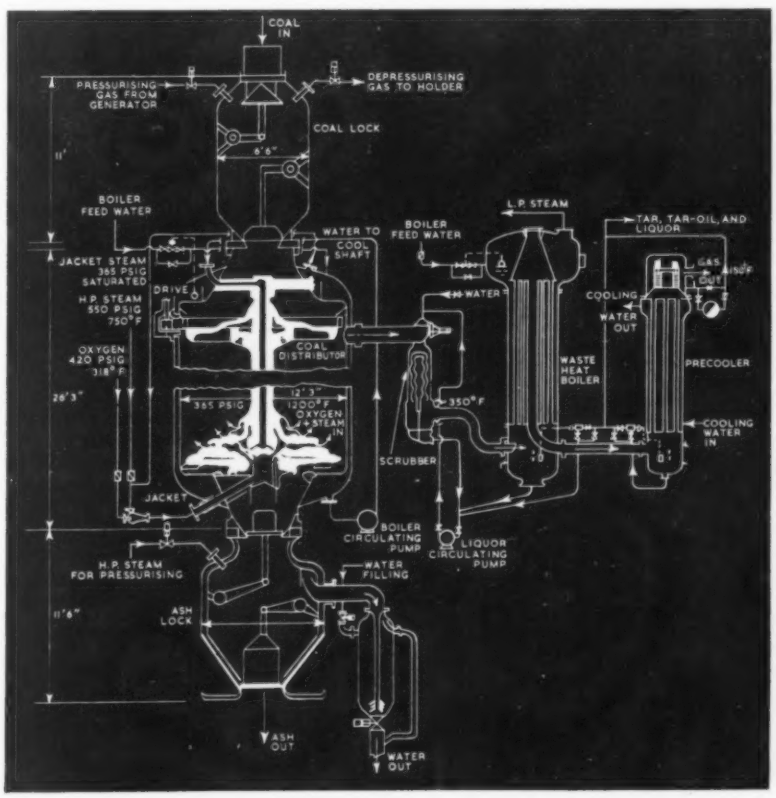


Fig. 4. Lurgi pressure gas generator with auxiliary equipment.

CO_2 content (this could be lowered further if required), a great advantage is its low dew-point—below −70°F. This ensures virtual freedom from corrosion of the gas transmission lines, a point of great importance if the gas is to be transmitted over any large distance.

(4) *Gas Re-forming: The Partial Combustion Plant.* From a synthesis point of view, methane is practically inert as nitrogen and argon. To minimise the inert content of the gas, it is desirable to re-form the methane and other hydrocarbons (referred to as C_nH_m) in the gas to carbon monoxide and hydrogen by treatment with oxygen and steam. The predominant reactions that take place are:

$$2CH_4+O_2=2CO+4H_2 \text{ (exothermic)}$$
$$CH_4+H_2O=CO+3H_2 \text{ (endothermic)}$$
$$2CO+O_2=2CO_2 \text{ (exothermic)}$$
$$CO+H_2O=CO_2+H_2 \text{ (exothermic)}$$
$$CO_2+CH_4=2CO+2H_2 \text{ (endothermic)}$$

The overall process is exothermic and the temperatures are, therefore, of necessity kept within narrow controlled limits.

Methane re-forming is not carried out on the gas for the Arge synthesis reactors; the reason for this will be explained later.

The "fresh" feed for the Kellogg synthesis reactors originates from three sources: (1) pure gas from the "Rectisol" plant; (2) Arge tail gas; and (3) tail gas from the Kellogg product-recovery plant. Typical analyses of these three gases are as follows, all figures being volumetric percentages.

	Pure gas	Arge tail gas	Kellogg tail gas
N_2	1.0%	2.3%	14.1%
H_2	59.9%	43.6%	30.8%
CO	25.0%	25.5%	1.9%
CO_2	1.0%	1.0%	18.6%
CH_4	13.0%	27.6%	27.2%
C_nH_m	0.1%	—	6.9%
H_2O	—	—	0.5%

Arge tail gas and pure gas are normally used in approximately equal quantities.

Combustion Plant

The partial combustion plant is divided into two identical sections, one serving each Kellogg reactor. The capacity of each, in terms of feed, is approximately 55,000 Nm^3/hr, or in terms of product gas 80,000 Nm^3/hr. Each section comprises a CO_2-scrubbing tower, two gas re-forming reactors and attendant auxiliary equipment. There is a common spare re-forming reactor, making a total of five reactors in all.

The incoming Kellogg tail gas is scrubbed to reduce the CO_2 content; this is done with water under a pressure of about 340 psig. Each tower has a diameter of 9½ ft and a height of 69 ft. The packing consists of Raschig rings. The water circulation rate of about 250,000 Imperial gallons per hour (per tower) is maintained by turbine pumps. The gas-laden water is de-pressured through Pelton wheels (which minimise the power requirements of the section) and aerated in a degassing tower built on similar lines to a small forced-draught cooling tower, before being recirculated to the towers.

After scrubbing of the Kellogg tail gas, the three gases are mixed to arrive at a mixture with an approximate composition of:

N_2	5.0%
H_2	48.7%
CO	20.0%
CO_2	1.9%
CH_4	22.4%
C_nH_m	1.9%
H_2O	0.1%

The feed gases enter the section at approximately 100°F, with the exception of oxygen, which enters at 360°F. The product gas normally leaves the section at 120°F.

Only one section of the plant, consisting of two reformers, will be described. The mixed gas is divided into two streams, one for each re-former. By heat exchange with reaction products, the "raw" gas is heated to about 800°F and then mixed with 400 psig saturated steam. A weight ratio of steam to hydrocarbons of about 2 to 1 is maintained. The steam/gas mixture has a temperature of about 700°F.

Stainless Steel Mix Nozzles

Further exchange with reaction products raises the temperature of the steam/gas mixture to about 1200°F. Control of this temperature is effected by partial by-passing of the heat exchanger. It is at this temperature that the gas mixture is introduced through mix-nozzles into the top of the reactor. In the mix-nozzles sufficient oxygen to maintain a weight ratio of oxygen/hydrocarbons of about 1 to 1—this ratio is rigorously controlled—is added. Sweeping steam is added with the oxygen to prevent burn-back into the oxygen lines in case of oxygen failure.

The nozzles are made of stainless steel with a ceramic tip and are cooled by water at 450 psig pressure. The reactors are also constructed of stainless steel and have an inner refractory lining and an external cooling water jacket. When the internal temperature is 2000°F, the steel skin temperature should not exceed 200°F.

Although the lower portion of the reactor is filled with nickel catalyst, the upper portion is empty. It is in this empty portion that the "oxygen reactions" take place. The "steam reactions" occur mainly in the catalyst bed. The reaction temperature exceeds 1700°F.

On leaving the bottom of the reactor, the hot gases pass first to a quench boiler and then successively to the two inlet gas preheaters. The temperature after leaving the second of these is in the region of 750°F. The 400 psig steam is raised in a waste-heat boiler in which the reformed gas is further cooled. Feed-water for this boiler is preheated by the gas and reduces the gas temperature to about 400°F—about 80°F above the dew-point of the gas.

A certain amount of carbon is produced in the reforming process and there is a possibility of catalyst dust being carried over with the gas. To prevent this from passing forward to the synthesis reactor, the product gas is washed in a tower 6½ ft in diameter and 24 ft high with 21,000 Imperial gallons/hour of water. The tower contains both baffles and bubble-cap trays, ensuring intimate contact between gas and water and consequent complete removal of solid particles.

Some of the water-vapour content of the gas is condensed in the scrubber. The rest of the water vapour is condensed in a shell and tube cooler, cooling water tube side, and removed from the gas in a knock-out drum. Part of this condensed water is used in the product gas scrubber and the rest as make-up for the CO_2-scrubbing system.

The composition of the exit (re-formed) gas is:

N_2	3.7%
H_2	61.6%
CO	22.2%
CO_2	7.2%
CH_4	4.7%
H_2O	0.6%

This composition can, of course, be varied according to the requirements of the synthesis units by control of the steam/oxygen ratio.

(Further articles on SASOL will be published, dealing respectively with (*a*) synthesis of hydrocarbons; (*b*) refining of main products; and (*c*) recovery of subsidiary products.)

THE TEDMAN SEPARATOR

A new type of centrifugal separator for particle size separations in the range $\frac{1}{8}$ in. to 0.1 mm. One interesting feature of this equipment is that it uses additional fluid to assist the separation process

by D. TEDMAN*

THE Tedman separator, like the hydraulic cyclone, has a high capacity, but treats sizes normally too coarse for centrifugal separation and can separate efficiently at $\frac{1}{4}$-in. size (or more in some cases) down to 140 mesh. Besides performing as a classifier, the separator is also a good concentrator of heavy minerals in sized or partly sized feed and can easily be adjusted by means of a valve to produce any ratio of concentration desired. For example, 5% or less of a primary-table-tailing feed can be removed as a concentrate.

A thick slurry feed is delivered tangentially to the main body of the separator, which is mounted with its main axis horizontal. The coarse sand present would normally all go to the coarse discharge outlet as in the hydraulic cyclone, but by feeding water to other tangential inlets only part of the sand goes to the coarse discharge outlet, the remainder, the fine or tailings product, spinning to the opposite outlet. Either of the products can be discharged from the separator in the thickened condition. When one is thickened the other is discharged with the bulk of the water, which is then drained from the solids and recirculated. The separation is controlled by the water flow rate and adjustments to this will fix the cut at any desired value.

High Capacity for Small Size

Capacity in relation to size is high. For example, a separator measuring only 4 in. in diameter and 30 in. long can handle 2-2½ tons/h of solids (dry weight) for a total flow rate of 50-60 gal/min. The head required is about 10 ft and the power consumption is low. Large tonnages of sands can be handled in multiple assemblies which are manufactured to treat up to 32 tons solids/h.

Essentially, the separator consists of a horizontal cylindrical vessel with conical ends. The inner wall of the cylindrical portion is in the form of a smooth coarse-pitch helix. Each turn of the helix is provided with a tangential inlet for introducing either slurry or liquid, usually water, into the main body of the separator. The main body is terminated at each end by a plain cone, smoothly connected internally to the helical groove. The cone apexes, which form the discharge orifices for the two products, are of different diameters, the smaller orifice being the one used to thicken the product. The cone ends are dowelled and bolted to the main body and can be fitted to either end according to which product is to be thickened (see Figs. 4 and 5).

The tangential inlets make an angle of about 85 degrees with the axis of the main body and direct the solids round the helical groove to the coarse or concentrate discharge outlet. At this point, to explain the position of the slurry feed and water inlets, the helical groove can be assumed to be divided approximately into two halves. The first half contains the lead-in portion or start of the helix and the slurry feed inlets are situated here. The cone outlet on this portion discharges the fine or tailing product.

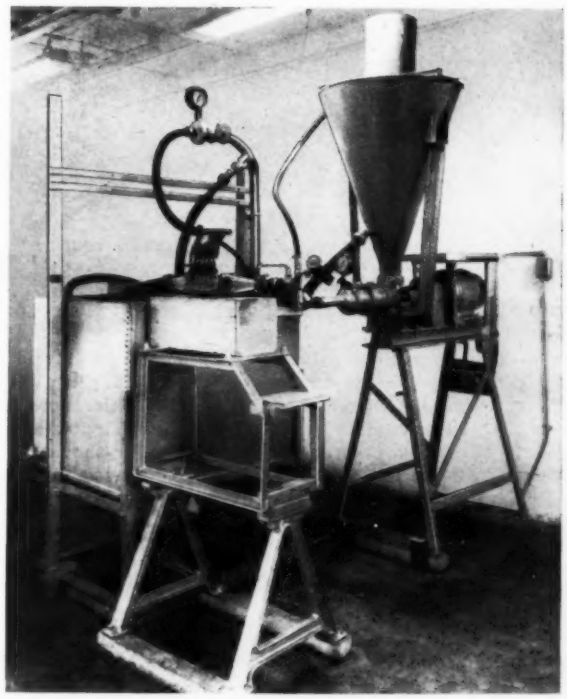


Fig. 1. Rig used for testing experimental separator. Note transparent conical end-pieces.

The other half of the helical groove carries the coarse or concentrate product and the water inlets. This coarse product is discharged through the conical portion at this end of the helical groove. The sand slurry containing about 30% solids is fed at about 7 ft/sec and at about 30 gpm to two or three adjacent tangential inlets near the start of the groove. This flow rate is usually enough to form a weak vortex with the feed slurry alone, and the sand will travel the length of the groove to be discharged at the coarse-discharge outlet.

The three tangential inlets nearest the coarse-discharge outlet, that is, at the end of the spiral travel, are fed with water at about 30 gpm total flow rate. This causes the solids discharge to the coarse outlet to decrease gradually over a period of some seconds until the steady state is established. At the same time, fine or tailing solids appear at the opposite outlet, spinning off the cone-discharge out-

* *Chemical and Mining Division of Vickerys Ltd.*

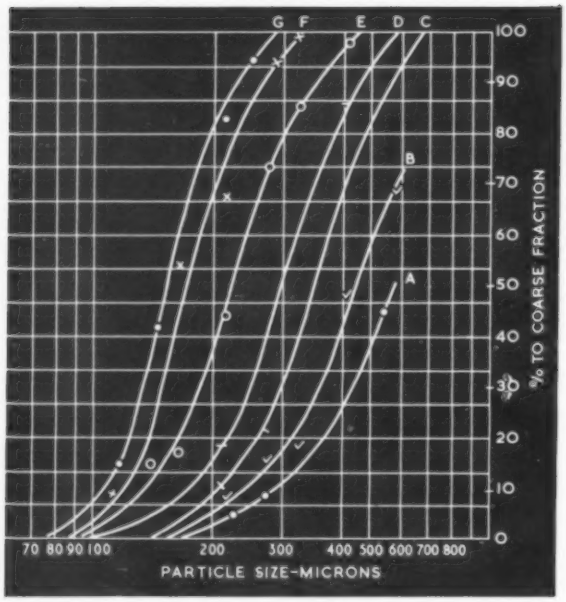


Fig. 2. Group of curves for a closely-sized −30 mesh feed consisting mainly of quartz with some coal or iron present in small amounts.

let wall. The quantity of tailings increases for some seconds and then continues discharging at a steady rate.

To adjust the separation, that is, to obtain more of the fine product and less of the coarse, or to obtain a higher ratio of concentration, the valve controlling the water flow is opened a little until the desired separation is obtained. After each valve adjustment a few seconds should be allowed to lapse so that the steady state is re-established.

If the slurry flow is increased by a considerable amount this will mean increasing the water flow to recover the original separation. To avoid increasing the water consumption a few tangential inlets following the slurry-feed inlets are closed so that there are "stopped turns" between the slurry inlets on one half of the spiral and the water inlets on the other half. This reduces the angular momentum of the solids as they travel through these sections of the helix and enables the water to carry back a larger amount of fines or tailings for the same rate of water flow, thus raising the size of the cut or the ratio of concentration.

Very little power is required to introduce feed and clean water—enough to deliver through $\frac{7}{8}$-in. diameter nozzles at 7 ft/sec being sufficient. Moreover, owing to the low velocities in the separator, there is little wear through abrasion.

Classification

If the sand feed consists of unsized particles of material of uniform specific gravity, or nearly so, the two products will be graded into coarse and fine sands. Fig. 2 shows a family of curves for a closely sized −30 mesh feed consisting mainly of quartz with some coal and iron present in small amounts. The graph shows the percentage extraction to the coarse product with particle size for various settings of the controls. The slope of the curves provides a measure of sizing efficiency. The levelling off of the curves at the upper and lower portions is due to the presence of light, coarse particles of coal and fine, heavy particles of iron in the feed. The coal tends to report to the fine product and the heavy-fine iron to the coarse product.

Similar curves can be obtained for any particular feed. If the object is pure sizing (all coarser than a certain mesh size to be removed) they will give the ratio of coarse product to feed. With the aid of the size-distribution curve for the feed, the amount of fines which must be lost to the coarse product for this separation can also be found. With long-size-range feeds this quantity is small but somewhat greater for a closely-sized feed.

To give an example, in one installation a single separator is fed with sand slurry at the rate of $2\frac{1}{2}$ ton/h containing 30% solids. Water is added at the rate of 25-30 gal/min, and this results in the removal of 5 cwt/h of coarse product which contains all the +30 mesh material present in the feed. The fine product is collected in storage tanks from which the water overflows. The coarse product is run to the ground, where it is carted and dumped after draining.

Fine Coal Cleaning

In spite of the flaky nature of shale particles, the closeness of the specific gravity of coal to unity makes shale/coal separation an excellent application for the separator.

One particular application is the removal of fine shale from the $-\frac{1}{4}$-in. portion of a Baum Jig cleaned-coal product. Some 6-7 cwt/h of shale product (ashing 60-70%) is removed, dewatered on a $\frac{1}{4}$-mm screen and dumped in the refuse hopper. The cleaned coal product is dewatered and deslimed on a $\frac{1}{4}$-mm screen at nearly 2 ton/h and delivered to a coal bin. The feed ashes 36-40% and the cleaned coal product ashes 15-20%. The shale remaining in the coal product is either in the form of middlings or thin flakes.

High throughputs are obtained by employing several separators working in parallel. The water and slimes return to the sump and from there to the water tower. The slime content is kept at a constant amount by continuously bleeding off a small portion of the tower water to waste.

A second type of coal-cleaning operation is one of desliming alone with a fine coal, where the ash content is mainly due to the presence of clay and fine pyrite. This requires clean or nearly clean water, which is not always available on a coal washery. If clean or nearly clean water can be used, then a bright coal is obtained from the coarse

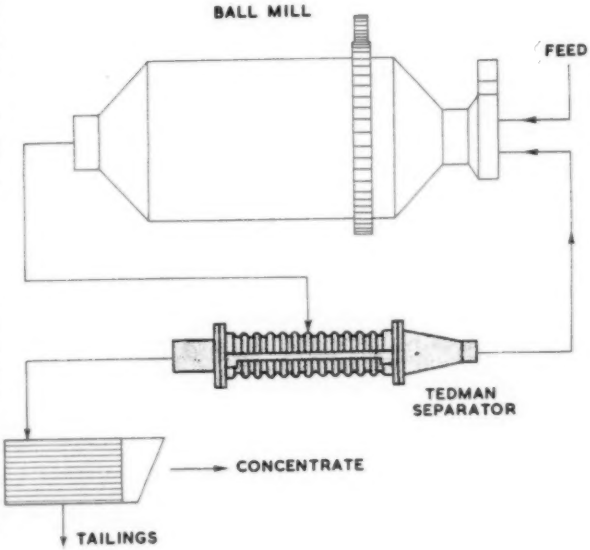


Fig. 3. Tedman classifier feeding a table concentrator from a ball-mill circuit.

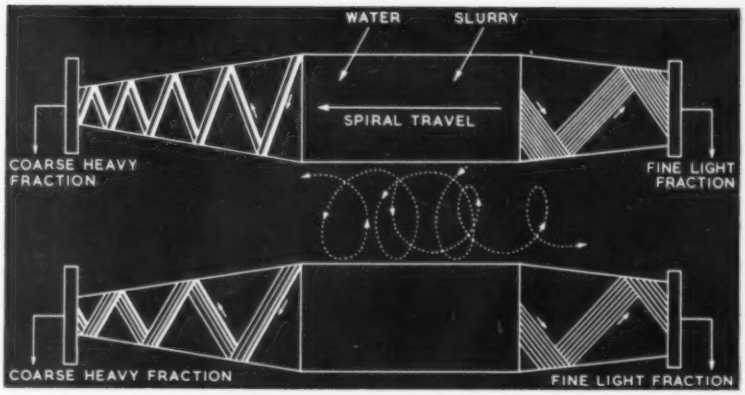


Fig. 4. The lower illustration shows the effect of reducing the water supply. The coarse, heavy fraction is increased and the fine, light fraction diminished. The spirals illustrate the trajectories of coarse, heavy material travelling to the left and fine, light material travelling right.

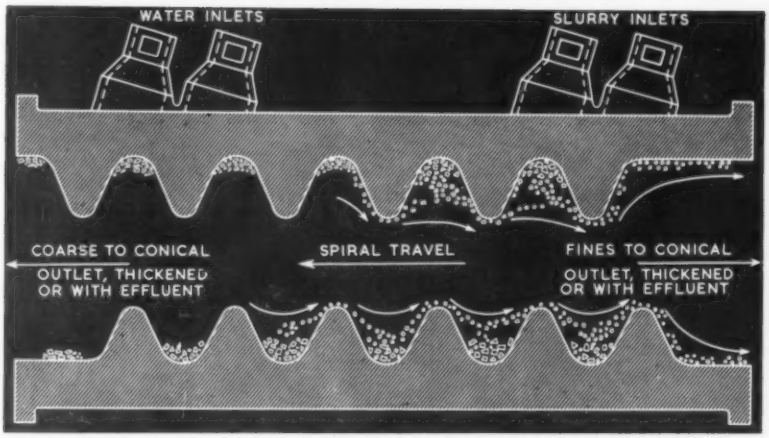

WATER INLETS
SLURRY INLETS
COARSE TO CONICAL OUTLET, THICKENED OR WITH EFFLUENT
SPIRAL TRAVEL
FINES TO CONICAL OUTLET, THICKENED OR WITH EFFLUENT

Fig. 5. Section of separator showing the movement of the fine and coarse particles along its helix.

discharge. This, when dewatered on a ½-mm screen, contains 8-10%, compared with the original feed of 20% ash.

When heavy minerals exist in the feed sands they can be obtained as a concentrate at the coarse-solids discharge. The degree of concentration depends largely on the amount of heavy mineral in the coarse sizes of the feed. This is increased by a single-screen cut and even more by a double-screen cut prior to separation. For example, primary table tailings from a tin mill can be concentrated up to as much as 50 lb. tin/ton for a recovery of about 40-45%. These tailings have originally been through a 20-mesh screen and the heavy minerals they contain are almost entirely middling particles which have been thrown off the table, possibly at times when overloading has occurred.

Where the heavier mineral is only a little higher in specific gravity than the gangue mineral, close sizing will, in most cases, considerably improve the concentration and recovery. Thus 2-mm garnet can be concentrated from quartz of approximately the same size for a recovery of at least 80%.

Desliming

Clean, washed, slime-free sands are produced at the coarse-solids discharge from sand feeds contaminated with slimes. This is possible largely because of the added water. The slimes separate in the feed half of the spiral body and are discharged with the bulk of the water at the fines-discharge port. The sands move into the coarse-discharge half, travelling round the helical groove, and any residual slimes clinging to the sands are thus removed, so that when the sands are discharged they are completely clean.

Conclusion

The Tedman separator is able to handle thin slurries at a fast rate without the need to pre-thicken. Thus a thin coal/shale slurry can be fed to the separator and a thickened shale product taken off.

Some values in old sands tailings dumps can be easily treated for recovery of values by this equipment. The concentrated product can go to a middlings ball-mill and then tabled for cleaning. Alternatively, the product can go straight to a table if the mineral is free. In the latter case the product is ideal for table feed, as it has been classified in passing through the separator; i,e., the gangue mineral in the concentrate product is coarser than the heavy mineral. Simple laboratory tests are employed to determine whether an economical concentrate can be obtained from these tailings.

The separator can be rigged-up anywhere, and is easily dismantled and transported to any site. Only one pump is required to recirculate the water if the slurry and water are gravity fed.

A most important application is the separation of a closely-sized sand feed into two sized products, coarse and fine. This type of screen will often blind screens with the large amount of near mesh sizes present. The separator works without this disadvantage and for a change in size cut it is only necessary to alter the water flow-rate.

In the June issue of *British Chemical Engineering* results of experiments conducted by the author on the effects of various operating conditions and design factors upon the behaviour of the separator and his conclusions on the mechanism of the action of the separator will be discussed in greater detail.

BURNING OF SULPHUR-BEARING MATERIALS FOR SULPHURIC ACID MANUFACTURE

The sources of sulphur available for sulphuric acid manufacture have been reviewed in a symposium organised by the Scunthorpe Group of the Institution of Chemical Engineers. Also discussed were developments in the production of sulphur dioxide*

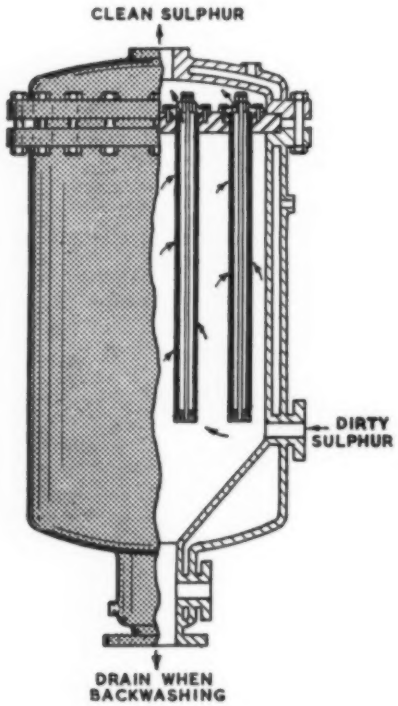


Fig. 1. Adams sulphur filter.

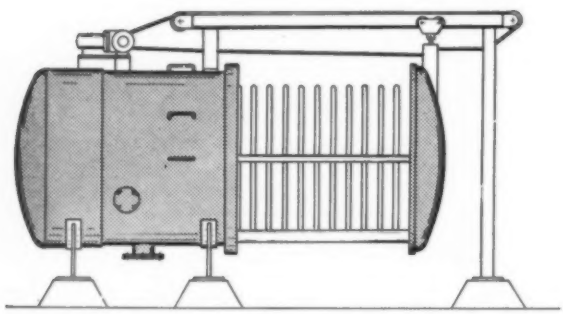


Fig. 2. Bird horizontal-type sulphur filter.

UNDOUBTEDLY, the simplest form of sulphur-bearing material is sulphur itself. The exact extent of its occurrence in the world seems to vary from decade to decade. In one decade we are in a crisis of acute sulphur shortage, and in another we are assured of supplies for generations to come. It seems we are now in the latter phase, and sulphur-burning plants are the most common "buy" at the moment.

Sulphur Filtration

Sulphur produced by the Frasch process from salt domes is one of the purest raw materials known. Prior to the sulphur shortage of 1948, a purity of 99.5% S was readily available for contact acid plants; in fact, the catalyst life was guaranteed only on this basis.

The impurities in sulphur are listed below with typical analyses:

	Bright %	*Dark* %
Moisture	0.05	0.10
Acidity	0.01-0.02	0.01-0.02
Ash	0.05	0.1-0.2
Carbonaceous matter ...	0.08	0.5

Moisture, ash and acidity are generally due to the action of the elements on open storage heaps; rain and winds are responsible for moisture and ash, while bacterial oxidation forms the acidic compounds.

The only steps taken to purify the sulphur were by an arrangement of underflow and overflow in the sulphur melter pits; the heavy inclusions were retained by the overflow and the lighter bituminous matter by the underflow. The pits were cleaned out annually. To protect the catalyst against dust, a simple filter of a bed of silica chips was interposed between the burner and the converter.

During the early 1950s the quality of sulphur tended to deteriorate, and acid manufacturers had no alternative but to take whatever grade was available. The fouling of waste-heat boilers and hot-gas filters caused decreased yields and lack of continuity of operation.

Our own experience of this period was that output fell, in four months' operation, from 250 tons a day to 200 tons a day. The financial loss was further aggravated by the loss of production while the plant was shut down to clean the filter, an operation which took 5 days. Added to this was the cost of reheating the plant with fuel oil, the quantity required being 1500 gallons. The total loss of acid

** This account summarises the salient points in the symposium papers contributed by Mr. S. C. Hale and Mr. Firth (Laporte Titanium Ltd.) and Mr. F. Heppenstall, Mr. G. C. Lowrison and Mr. C. L. Vickers (Fisons Ltd.).*

production was estimated to be approximately 2400 tons.

To overcome these serious losses, many companies installed sulphur filters, which are available in several types and sizes. All commercial sulphur filters are of enclosed pressure, steam-heated design. The main differences are in type and arrangements of filter media or the method of cake removal. The most popular filters are (1) Adams filter; (2) Bird filter; (3) Niagara filter; and (4) Kelly filter. The Adams is a porous tube filter and the rest are leaf-type filters.

Adams filter (Fig. 1). This is an enclosed batch pressure filter. The sulphur is pumped into the side of a steam-jacketed shell and filtered through vertical porous-carbon tubes. The tubes are precoated by adding diatomaceous earth to the filter feed at high rate at the commencement of the filter cycle until a sufficiently thick coat is formed. The rate of addition is then reduced to about 1 lb/ton of sulphur. The cake is removed without filter disassembly by backwashing with 50 psig steam. The manufacturers claim that this operation can be performed in $\frac{2}{5}$ minute. A filter cycle of eight hours is recommended with $\frac{1}{16}$-in. precoat.

The filter is available in three sizes:

17.5 sq. ft filter area	5 tubes
31.0 sq. ft „ „	9 tubes
75.0 sq. ft „ „	21 tubes

American claims state that the capacity of the five-tube filter is about 50 tons/day, or 0.3 sq. ft/ton/day sulphur filtered. This appears to be an extremely ambitious rate but, of course, the rate must also be related to the purity of the sulphur fed.

Bird filter (Fig. 2). This filter consists of a steam-jacketed cylindrical shell mounted horizontally with multiple pressure leaves mounted across the diameter on a manifold and rack. All are attached to a movable head which is withdrawn for cake removal. The leaves, which are covered with stainless-steel cloth, are easily removable according to the manufacturer's claim. The cake is removed by withdrawing the leaves and tapping the edges of the filter. Models are available with filtering areas from 60-1635 sq. ft, all working at a pressure of 75 psig. The filter area recommended for bright sulphur is 1 sq. ft/ton/day and for dark 2 sq. ft/ton/day.

Niagara filter (Fig. 3). Two types are available, one a standard vertical filter and the other the "H" horizontal filter. Both are enclosed steam-jacketed batch-type pressure filters. In the vertical type, cake removal is achieved by opening the top dome, tapping the filter screens to make the cake drop and removing manually through a clean-out hole near the bottom. In the horizontal model, the filter screens are mounted on a carriage which is withdrawn from the shell and the cake removed by tapping the edges of the screen frames.

Size and Capacities

Vertical	19.2 sq. ft— 960 sq. ft
"H" Horizontal	85.0 sq. ft—1332 sq. ft
Operating Data	65 psig

Kelly filter (Fig. 4). This is the only filter of which we have operating experience. It is a steam-jacketed, horizontal tank with filter leaves mounted along the cylindrical axis. The sulphur to be filtered is pumped into one end of the vessel and filtered through the precoated stainless-steel-wire cloth-covered leaves. The filter cake is dried by blowing with compressed air, releasing the pressure and rolling the filter-leaf carriage from the shell. Although it is claimed that the cleaning operation can be carried out and the filter returned to service in 15 minutes, it is our experience that 30 minutes are necessary.

Filter aid. The diatomaceous filter aid is mixed with molten sulphur and recycled through the filter until a cake of $\frac{1}{16}$-$\frac{1}{8}$ in. is deposited on the filter leaves.

Materials of Construction. The filter is of mild steel; the leaves are of welded steel covered with 24 × 110 mesh 316 stainless-steel-wire cloth caulked with asbestos caulking. We have found it more economical to use mild-steel leaves bolted to the frame, mainly because the stainless steel suffered mechanical damage and the bolted construction formed a more reliable seal.

Sizes and capacities. Sizes range from 3 to 400 sq. ft.

Operating data. Designed for an internal pressure of 55 psig and operating steam pressure of 60 psig. The average filtration rate is stated to be 1 ton sulphur/day/sq. ft of filtering area. We have found it possible to filter nearly 2 tons sulphur/day/sq. ft by using $\frac{1}{2}$ lb/1 lb of filter-aid/ton of sulphur and by working on filter cycles of 5-7 hours. This is not possible with Texan dark sulphur, when it is necessary to use a 50% admixture of bright sulphur to enable all sulphur fed to the plant to be clean.

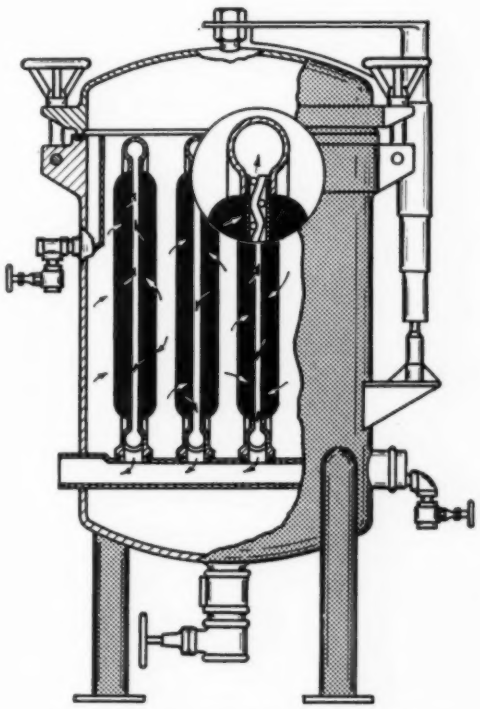


Fig. 3. Niagara vertical-type sulphur filter.

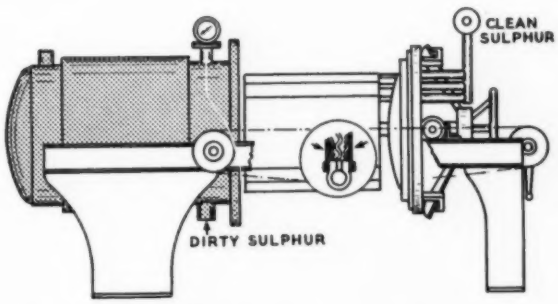


Fig. 4. Kelly sulphur filter (shown with leaves withdrawn for cleaning).

Economies. At the present prices of bright and dark sulphur, the extra cost of filtration of dark sulphur compared with bright can be easily borne, so that it is economically better to buy dark sulphur for filtration. Some of the American sulphur suppliers have installed expensive filtration equipment and are now finding that many users are demanding the cheaper dark sulphur. It would be difficult to make an economic case for filtering bright sulphur, but filtration does protect the waste-heat boiler and obviates the necessity for cleaning and shot-blasting the boiler tubes. If the boiler capacity is critical, a thin deposit on the tubes can cause a serious loss of heat transfer, entailing a drop in production; shot-blasting can be expensive and time-consuming. Thus, if constant high production is required, it is desirable to filter all sulphur. Having produced the sulphur in a form practically free from impurities, a sulphur-burning plant can run for a very long time without a shut-down, the determining period for a shut-down nowadays being the statutory frequency of examination of the waste-heat boilers (i.e., 14 months).

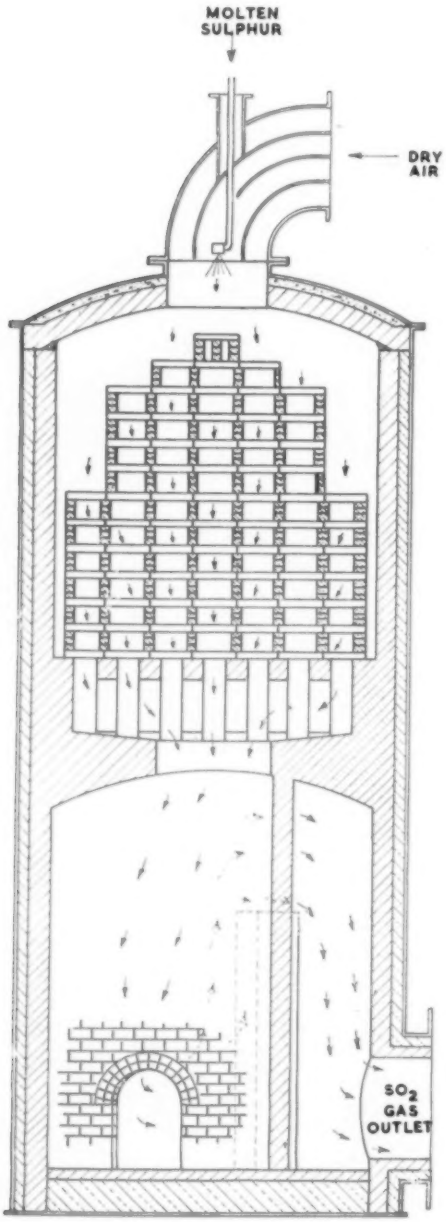


Fig. 5. Vertical cascade-type sulphur burner.

Burning of Sulphur

The burning of sulphur to produce sulphur dioxide can be considered to be a two-stage operation; (1) vaporisation; and (2) the combination of the volatilised sulphur with oxygen to form sulphur dioxide.

The factors which can influence the burning are: (a) the temperature inside the burner; (b) the amount of combustion air added; and (c) the retention time allowed to obtain a homogeneous gas.

The control of temperature inside the burner presents no problem, being only a question of controlling either the sulphur or air supply. The retention and mixing time is determined by the design of the burner, which should provide for an intimate and rapid mixing. The amount of combustion space normally provided varies with the type of burner, but is in the order of 20-60 cu. ft/ton of sulphur burned a day.

The three main types of sulphur burner in use at the present time are: (1) rotary type, i.e., Glen Falls type; (2) cascade type; and (3) spray type.

The cascade type, which can be either vertical or horizontal (Figs. 5 and 6), consists of a mild-steel shell lined with firebrick and insulating brick, capable of withstanding a working temperature of 1500°C. Both the vertical and horizontal operate similarly; the molten sulphur and combustion air is fed into the section of the burner containing a firebrick chequer, the sulphur vaporising and burning as it runs over the chequer-work. In both types a combustion space is provided for, integral with the burner. Maintenance on this type of burner is very small, and it is reported that such burners have operated for periods of up to 15 years without needing extensive repairs to the lining or shell. In our case we have replaced part of the lining and the whole of the chequer brick in six years' operation, although the need for replacing the chequer was caused by its becoming choked with silicious impurities prior to our introduction of sulphur filtration.

The spray type of burner (Fig. 7) consists of a horizontal mild-steel shell lined with insulating and fire brick. As a rule, the first part of the burner is followed by a section containing alternate top and bottom baffles to promote mixing of the gas. Liquid sulphur is sprayed or atomised into the combustion space, atomisation being obtained either by pump pressure alone or in conjunction with compressed air. The spray nozzles are usually fabricated of mild steel. The capacity of the burner is varied by using different nozzle sizes. It is important with this type of burner that the temperature of the sulphur being fed be maintained within fairly close limits in order that the viscosity remains constant, minimum viscosity being obtained at 155°C (see Fig 9). In the case of cascade burners, the waste-heat boiler is always located outside the burner, whilst in the spray type the waste-heat boiler is frequently an integral part of the burner, although this is not always the case.

Sulphur fed to the spray gun should be free from solid impurities, and it would seem to us that it is preferable with this type of burner to use filtered sulphur in order that proper atomisation can be obtained. Even when filtered sulphur is being used, we understand that it is necessary to clean the nozzle approximately every two hours, although with the present sulphur guns a cleaning device is incorporated and the nozzle can be cleaned while the gun is in fact in operation. A partly blocked nozzle affects the atomisation, and there is a danger of pools of sulphur

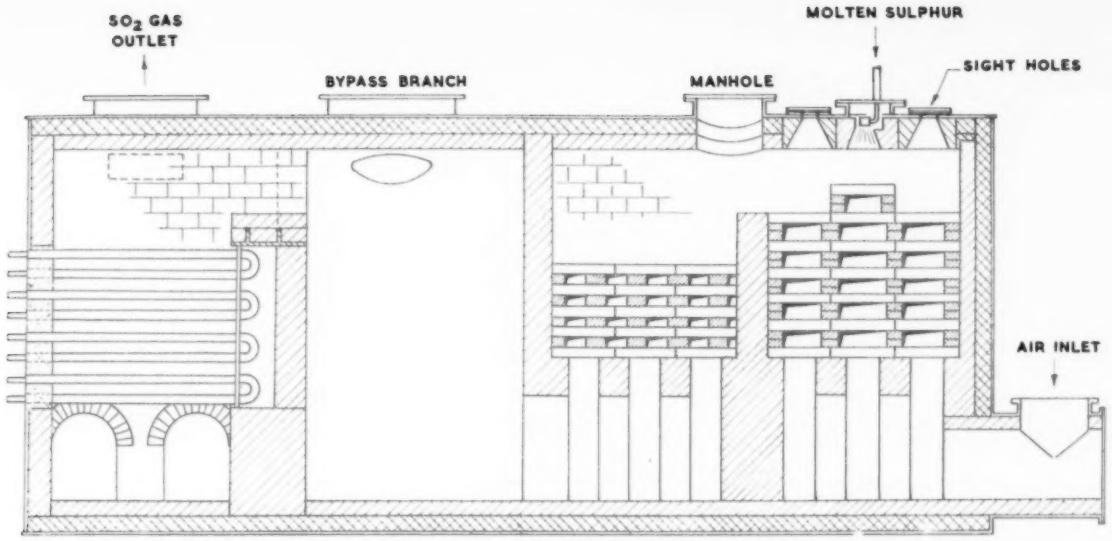


Fig. 6. Horizontal cascade-type sulphur burner.

accumulating in the cooled section of the burner. These pools then ignite and burn off, causing fluctuating gas concentrations. As the spray-type burner contains very much less brickwork than the cascade type, it can be brought on stream in a fairly short time, but for the same reason it suffers the disadvantage that by comparison with the cascade burner it loses its heat much more quickly, and cannot be shut-down for such long periods as the cascade burner without oil firing.

Both types are started up by oil firing the burner until the brickwork is up to the ignition temperature of the sulphur (i.e., 475°C). A further advantage of the cascade burner is that the amount of brickwork acts as a heat reservoir, and this heat can be used for bringing the catalyst bed of the converter up to its biting temperature, thereby protecting the catalyst bed from the water generated in the combustion of the oil whilst the catalyst bed is below the dewpoint for these products of combustion.

The rotary type of burner (Fig. 8) is normally used for burning small tonnages of sulphur, and does not normally deal with quantities exceeding 20 tons a day. The general design of the rotary burner is very simple; it consists of a horizontal mild-steel cylinder with cast-iron conical ends which rotates on trunnions to keep the interior surfaces wet with molten sulphur from the pool in the bottom of the burner. The depth of this pool is normally kept just below the gas outlet level, and is maintained by feeding solid sulphur into the burner via a screw feeder. Primary air is admitted to the burner at the feed end, and secondary air is admitted at the outlet of the burner just before the volatilised sulphur vapour passes into the combustion chamber.

The amount of sulphur that can be burned in this type of burner is dependent upon the surface area of the burner and the quantity of air admitted. A burner 4 ft in diameter will consume approximately 1 ton of sulphur a day/foot length, with an air draught of approximately $\frac{1}{2}$ in. water gauge, measured at the discharge end of the burner. A combustion chamber is a necessary adjunct to this type of burner, as the gases leaving it consist in the main of volatilised sulphur vapour, and at the inlet to the combustion chamber secondary air is admitted in order to complete combustion.

A New Type of Burner

Another type of burner has recently been designed in America for burning small quantities of sulphur, consisting of three superimposed compartments: a melter, a liquid feed tank and a combustion chamber. The liquid sulphur is allowed to discharge into the combustion chamber and the feed is so designed that a constant level of sulphur is maintained in this chamber. The burning takes place on the

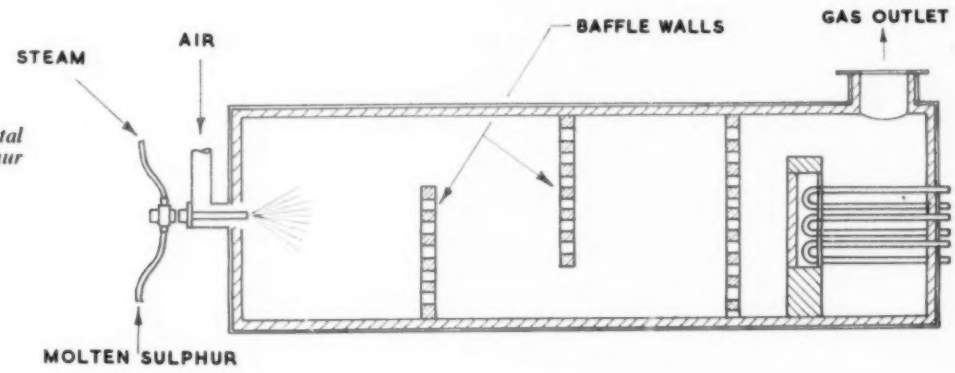


Fig. 7. Horizontal spray-type sulphur burner.

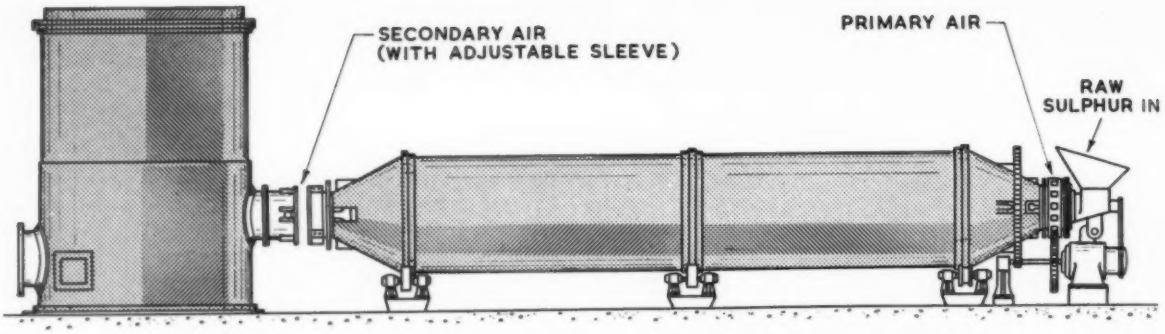


Fig. 8. The Glen Falls rotary burner used for burning small tonnages of sulphur.

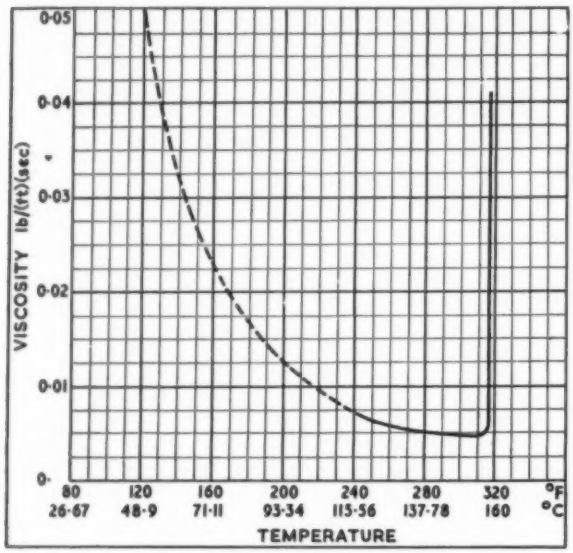


Fig. 9. Viscosity of liquid sulphur.

surface of the liquid sulphur, and air for combustion enters into the side of this chamber. Such a burner is not suitable for sulphur containing carbonaceous matter, as this tends to float on the surface of the sulphur, forming a blanket which greatly reduces the burning rate.

Scum Formation

The rotary type of burner is very simple to operate when using sulphur free from bituminous matter, but with bituminous sulphur a scum forms on the surface of the sulphur and slows down the burner rate. To overcome this, it is advisable to have a slight slope towards the exit end of approximately one in three hundred, and to allow a small continuous overflow of scum from the sulphur pool arranged to fall into a water-filled quench tray. To assist in the removal of the scum, small flights can be fitted on the cone at the exit end of the burner.

The burner is simple to maintain, and shell life has been found to be of the order of 5 years. It is necessary from time to time to clean out the burner. The frequency of this depends upon the purity of the sulphur being used. From experience with the burning of the present-day quality of American sulphur, a burner of 16 ft in length and 4 ft in diameter requires to be cleaned out at intervals of approximately 3500-4000 tons. The cleaning process can be completed in about 8 hours.

We have stated earlier that the capacity of this burner is dependent upon the size and air admitted, and there is no doubt that this could be improved upon by lagging the shell and installing lifters, to give a higher temperature in the burner and the lifters and better sulphur distribution.

(To be concluded)

Zone Refining of Metals

NOTHING, perhaps, is simpler to imagine, said Mr. N. Parr in a lecture on zone purification given to the London Section of the Royal Institute of Chemistry recently, than purification by directional crystallisation. The efficiency of the technique, however, depends largely on recent developments in high vacuum equipment, superpure atmospheres, high-frequency heating and ultra-fine methods of analysis. Although modern developments may be said to date from 1952, when Pfann published a description of the technique and an analysis of the theoretical factors involved, the phenomenon of zoning must have been known to the ancients. The harmfulness of segregation in the centre of large ingots has long been recognised in the foundry and catered for by providing false heads which are subsequently cropped and discarded.

Whether or not purification by zoning is possible depends largely on the nature of the phase equilibrium diagram. The ratio of the slopes of the liquidus and solidus lines at the extreme ends of such a diagram is termed the segregation coefficient. When a molten zone traverses a length of material whose segregation coefficient (i.e., the ratio of the concentration of impurities in the solid to that in the liquid) is less than one. The material deposited behind the zone will be of greater purity and the liquid will contain more and more impurity. Impurities tending to raise the melting point of the solvent (segregation coefficient greater than one) follow a reverse and much less efficient procedure as the moving liquid zone becomes progressively purer. Several passes of the molten zone may be made in the same and in alternate directions. Not all impurities can be removed by zone purification, e.g., boron in silicon, but an impurity may be converted to the oxide or other compound, which can be removed by zoning.

Perhaps the most recent application of the technique is in the atomic energy field, where it is necessary to remove impurities from new uranium fuel elements and fission products from spent ones. Many metals including tungsten, rhenium, titanium and zirconium have been purified and their mechanical strengths thereby greatly improved. Germanium, silicon and gallium for semi-conductor work have also been purified and the technique extended to the purification of organic compounds for use as standards.

The control room of the British Petroleum Company's Llandarcy oil refinery, South Wales.

THE APPLICATION OF AUTOMATIC PROCESS CONTROL TO CHEMICAL ENGINEERING

This is the first of a series of articles on automatic control designed to outline the principles of control theory and show how they may be applied to chemical and process plant practice

by N. J. HASSETT, Ph.D., M.I.Chem.E.

A PROCESS is usually a combination of component processes grouped together and the word process can be used to denote any one or any coherent group of such processes. A single primary or elemental process, termed a process stage, becomes a complete unit for process control study.

So defined, a process stage falls into one of two categories, batch or continuous, according to whether the change occurs without transportation, or in a stream of material such that at any fixed point the conditions in the stream lie within prescribed limits. A process can then comprise batch-process stages only, continuous stages only, or a combination of both. The automatic control of a batch process is usually more difficult than that of a continuous process, and this coupled with the time lost in emptying, cleaning and recharging, as well as intermediate storage requirements, encourages the use of continuous processing. The preliminary study of process control will, therefore, deal with continuous processes. A process may be analysed, as in the following examples, in terms of its component process stages. The elements referred to are those defined in the glossary of terms on p. 254.

Example 1

Process analysis; saturated steam from conditioned water (in a boiler plant)

First process stage, water feeding.

Controlled medium ...	Water
Control agent ...	Water
Controlled variable ...	Level
Other process variables	None

Second process stage, steam raising

			Potential alternatives
Controlled medium ...	Steam	:	Water
Control agent ...	Fuel	:	Fuel
Controlled variable ...	Pressure	:	Temp.
Other process variables	Temp.	:	Pressure

Subsidiary process stage, combustion.

Controlled medium ...	Stack gases
Control agent ...	Secondary air
Controlled variable ...	CO_2 percentage
Other process variables	O_2 and CO percentages, temperature

Another way of regarding the system is to consider the steam raising as a main process stage and the others as subsidiary or auxiliary process stages.

Nature of Disturbances

With all relevant factors and conditions steady, a uniform product will leave a continuous-process stage at a constant rate. Such conditions are rarely, if ever, realised in practice. Disturbances continually arise and must be counterbalanced if the product is to remain uniform. The control of a system is, in effect, the application of a counter disturbance to nullify the effect of other disturbances. Therefore, the study of process control involves, primarily, the reaction of a process stage to a disturbance—also termed input signal—which may take any of the following forms:

(1) A step change ... This is a disturbance applied suddenly and then held at a constant value.

GLOSSARY OF TERMS

Process material or controlled medium	The material being processed, as distinct from additives or control agents. It may change its physical and chemical nature during the process.
Control agent ...	An agent, the added rate of which is varied to control the progress of a process. It may, for example, be heat or a chemical reagent, and there may be more than one control agent in a process stage.
Process variables ...	Characteristics which indicate the progress of a process. There are often more than one in a process stage. Examples are pressure, temperature, *p*H and viscosity.
Controlled variable ...	That process variable chosen as defining the condition of the process material.
Deviation	Any difference between the value of the controlled variable and its desired value.

(2) A ramp change ... A disturbance of steadily increasing value.

(3) A sinusoidal change An oscillating or cyclic disturbance.

(4) A transitory change (impulse signal) ... ... A transitory disturbance of undefined nature.

If the disturbance arises as a result of a change associated with the control agent, it is called a supply-side disturbance, while if it arises by virtue of a change on the process-material side, it is called a demand-side disturbance. Either one, or a combination of supply and demand disturbances may occur, and the net disturbance may take the form of any of the input signals listed above.

Theory of Process Control

Self or inherent regulation, potential deviation. The theory of process control is based on inherent regulation. This simply means that the process will adjust itself to a new equilibrium if a sustained disturbance of constant magnitude is imposed. This leads to the concept of potential deviation. A step disturbance tends to bring the system to a new state of equilibrium which is determined by the magnitude of the disturbance and the characteristics of the process. This new state of equilibrium is theoretically only attained after an infinite time, and the ultimate displacement in value of the controlled variable is called the potential deviation, written as θ_p. These remarks define the nature of a process stage amenable to automatic control.

If a disturbance of varying magnitude enters a system, the instantaneous value of the disturbance at any given moment is designated by θ_1. The value of the deviation at that same moment is designated by θ_2, but θ_2 is not necessarily related to the value of θ_1, because it is the resultant of past history. This is clear if we consider the moment of application of a step disturbance. At that moment there may be both a deviation as a result of earlier disturbances now gone, and insufficient time to recover normal equilibrium. It is evident that this residual deviation need have no relation to the new step disturbance.

Each transient value θ_1 of a disturbance has, however, its equivalent potential deviation θ_p, which is defined by the new state of equilibrium that would obtain if the disturbance remained constant. This potential deviation can be evaluated by a simple stoichometric calculation as illustrated in the following example (for key to the rationalised abbreviations to be used throughout these articles, see List 1).

Example 2

Potential Deviation

Live steam at 50 psig is injected into a flow of water of 2000 lbph and heats it from 70°F to 190°F, which is the required temperature (desired value). Define the nature and calculate the magnitude of the input signal and potential deviation in each of the following events:

(*a*) Steam remains constant, water rate increases by 83 lbph.

(*b*) Water rate remains constant, steam pressure falls to 48 psig.

(*c*) Original conditions, except that water inlet temperature falls to 65.2°F.

Standard heat demand (load)=2000 (190−70)=240,000 Btuph.

(*a*) Input signal=83 lbph water (a demand-side disturbance).

LIST 1

Rationalised Abbreviations

(Terminal p denotes pounds force, otherwise p=per.)

psi= pounds force per sq. in.—pressure differential
psig = pounds force per sq. in.—gauge pressure
psia = pounds force per sq. in.—absolute pressure
gph = gallons per hour
gpm = gallons per minute
gps = gallons per second
lbph = pounds mass per hour
Btu = British thermal unit(s)
Btuph = British thermal units per hour.

(Although some of these abbreviations may be unfamiliar, they are very convenient in use.)

New equilibrium temperature rise $= \frac{240{,}000}{2083} = 115.2°\text{F}$.

New temperature=70+115.2=185.2°F.

Potential deviation θ_p=185.2−190=−4.8°F.

(*b*) Input signal=−2 psi steam pressure (a supply-side disturbance).

For a small pressure difference, steam input can be taken as being directly proportional to pressure.

New heat input=(48/50) (240,000)=230,400 Btuph.

Alternative input signal=230,400−240,000=−9600 Btuph.

Equilibrium temperature rise $= \frac{230{,}400}{2000} = 115.2°\text{F}$.

As in (*a*), therefore, $\theta_p = -4.8°\text{F}$.

(*c*) Input signal=−4.8°F water inlet temperature (a demand-side disturbance).

Since the water and steam inputs are unchanged, the temperature rise of 120°F is unaffected.

New equilibrium temperature=65.2+120=185.2°F.

$\theta_p = -4.8°\text{F}$ as before.

From Example 2 it will be noted that what is effectively the same input signal can be obtained from different disturbance sources and expressed in very different terms. Thus the same θ_1 is 83 lbph of water,
−9600 Btuph,
−4.8°F,
or −2 psi steam pressure, each giving the same potential deviation of −4.8°F. This anomaly in units is undesirable and makes the theoretical treatment of process control unnecessarily confusing to

the chemical engineer who is accustomed to working in consistent or rational units, even when dimensional plant constants are introduced to balance the equations where necessary. The present treatment will therefore differ from that usually found in literature dealing with automatic control, in that rational units will be employed. Where necessary, due comparison will be made with other texts.

Most Convenient Unit

The most convenient unit for correlation of disturbances is that of the controlled variable, which, of course, is that of the deviation. The magnitude of any disturbance is then the equivalent potential deviation, which can be evaluated from the known characteristics of the process.

Disturbances from different sources may be converted by disturbance correlation factors to a common reference unit, which is usually that of the measured variable. The factors will not appear in manipulated process control equations. They are simply used before and after manipulation to convert disturbances into equivalent signals and conversely. There is no point in complicating them by giving them dimensions. They will always relate back to their original definition as laid out in the data appertaining to the particular system under consideration.

The correcting disturbance applied to negate involuntary disturbances is usually a valve adjustment. This valve adjustment can also conveniently be expressed in the same consistent units. The term involuntary disturbance embraces all disturbances other than the correcting disturbance, and includes changes in offtake which, in point of fact, are voluntary.

Example 3

Disturbance Correlation Factors

In a foodstuffs factory, 500 lbph of 90% acetic acid is being diluted with water to 5% concentration. A control valve on the water line gives a flow rate of 10,000 lbph when $\frac{1}{4}$ open, with the water pressure at 40 psig. The water flow is substantially directly proportional to pressure and to valve opening, for changes within 25% of normal process conditions.

Express the following disturbances in consistent units:

(*a*) (i) Unit change in concentration of strong acid.
(ii) A change to 93%.

(*b*) (i) Unit change of rate of strong acid feed.
(ii) A change to 493 lbph.

(*c*) (i) Unit change of water pressure.
(ii) A change to 35 psig.

(*d*) (i) Unit change of valve setting.
(ii) A change from 0.64 full open to 0.52 full open.

The consistent unit is that of the measured variable, i.e., percentage acidity of product. The normal operating conditions are first evaluated and the relationships then follow from simple stoichometric considerations.

The normal water requirement, for dilution to 5% is calculated thus:

500 lbph 90% acid make 500 (90/5)=9000 lbph of 5% acid.

$\therefore$ Water requirement=9000−500=8500 lbph. The normal valve opening for this water requirement $= \frac{8500}{10{,}000} \times \frac{3}{4}$ open

$= 0.64$ of full open.

(*a*) (i) A change of 1% absolute in strong-acid concentration will cause an equilibrium change of (1/90)×5%=0.06% acidity.

This is the input signal or disturbance per unit change of strong-acid concentration, expressed in consistent units, and the disturbance correlation factor F_c, relating 1% strong-acid concentration to percentage acidity of product is 0.06.

(ii) A change of 3% (absolute) in strong-acid concentration gives an input signal of

$$\theta_1 = 3 \times F_c = 3 \times 0.06 = 0.18\% \text{ acidity.}$$

(*b*) (i) A change in strong acid rate of 1 lbph causes an equilibrium change of (1/500) 5=0.01% acidity.

i.e., $F_A = 0.01$.

(ii) A decrease in rate of 7 lbph gives an input signal of

$$\theta_1 = -7 \times F_A = -7 \times 0.01 = -0.07\% \text{ acidity.}$$

(*c*) (i) A change in water pressure of 1 psi causes a change in water rate of (1/40) 8500=213 lbph.

This, in turn induces an equilibrium change of $-\left(\frac{213}{9000}\right)5 = -0.12\%$ acidity. The negative sign indicates that increase of water pressure (water rate) causes decreased percentage acidity.

$$F_P = -0.12.$$

(ii) A decrease in pressure of 5 psi is then equivalent to an input signal of

$$\theta_1 = -5 \times F_P = -5 \times (-0.12) = +0.6\% \text{ acidity.}$$

(*d*) (i) A change in valve setting of full open (or 100% valve movement) changes the water flow by 10,000÷$\frac{1}{4}$ or 13,3000 lbph. This, in turn, causes an equilibrium change of $-(13{,}300/9000) \times 5 = -7.4\%$ acidity. As before, the negative sign indicates that a positive valve movement (opening) results in a decreased acidity.

Then, $F_v = -7.4\%$.

(There is an apparent anomaly here, since, with the valve shut, the acidity of the product will be 90%. We are concerned, however, with relatively small changes in the region of 5% product acidity, where this proportionality factor holds good for all practical purposes.)

(ii) A decrease of 0.12 full open (12% negative valve movement) is then equivalent to an input signal of

$$\theta_1 = -0.12 \; F_v = -0.12 \times -7.4 = 0.89\% \text{ acidity.}$$

In Example 3 the process or demand load is the required water flow. The control agent, governed by valve adjustment, is water. The process is dilution of acid, which is the process material. If the example had been formulated differently, and a flow of water were to be acidified by a controlled flow of strong acid, the strong acid would have been the control agent, and the process material would have been water changing to dilute acid.

Example 4

Valve Correction

In Example 3, the strong-acid concentration rises to 94%, while its supply rate has fallen to 480 lbph. The water pressure is at 37 psig. What is the necessary valve correction and absolute valve setting to maintain the product at 5% acidity?

Supply acid concentration signal $= +4 \times F_c$
$= 4 \times 0.06$
$= 0.24\%$ acidity

Supply acid rate signal $= -20 \times F_A$
$= -20 \times 0.01$
$= -0.20\%$ acidity

Water pressure signal $= -3 \times F_P$
$= -3 \times (-0.12)$
$= +0.36\%$ acidity

Total input signal=0.24−0.20+0.36=0.40% acidity.
Required valve correction=−0.40% acidity.
Actual valve movement=$-0.4/F_v = -0.4/(-7.4) = 0.054$ of full open.

New valve setting=0.64+0.054=0.68 of full open.

SUPPRESSION OF AIRBORNE EFFLUENTS

Many aspects of atmospheric pollution and its prevention were discussed at the London conference on the engineer's contribution to clean air, recently organised by the Institution of Mechanical Engineers. Selected parts of the proceedings are published below.

IN a paper dealing with the performance and scope for improvement in power-station equipment for the removal of sulphur dioxide from flue gases, R. LL. REES described the pilot plant for the Fulham-Simon-Carves cyclic ammonia process which has been installed by the Central Electricity Authority and Simon-Carves, with the co-operation of the Fuel Research Station, at North Wilford power station. The plant handles half of the gases from one of the boilers at the station—about 1.5 million cu. ft an hour. The process originated with an investigation at Fulham power station begun in 1939 in conjunction with Simon-Carves, and aimed at developing the manufacture of ammonium sulphate and sulphur by washing flue gases with ammonia liquor from gas-works and coke ovens. After cessation of activities during the war, an investigation on a small scale was started at the Fuel Research Station in 1948 to assess the potentialities of the process in comparison with other known methods of washing flue gases. The gist of the technique is that liquor bled from the circulating system is heated under pressure with sulphuric acid to produce ammonium sulphate and sulphur. Although a number of improvements can be expected in this part of the technique, the major field of inquiry at present lies in the design of the scrubbers. These are required to remove nearly all the sulphur dioxide from the gases, while retaining all but a trace of the volatile ammonia. The technique of controlling the plant within these fine limits of operation is being studied with the aid of an instrument that has been specially designed (Simon-Carves, Fulham Borough Council, Parker and Gillham, 1946).

The economics of the process, Mr. Rees said, will depend largely upon the cost and availability of ammonia liquor, upon the price that can be obtained for the ammonium sulphate, and upon the cost of maintaining the plant. The all-in cost may be much less than that of the Battersea process. The amount of sulphur obtained is small and comes from thiosulphate. It is unlikely that the amount of ammonia liquor that will be available will suffice to wash the gases at more than about half-a-dozen power stations.

The great difficulty that arises in all methods of washing flue gas is that, as the gas is cool and laden with carbon dioxide and condensed water droplets, it has a density which makes it fall to ground level very much nearer the point of emission than when it is discharged unwashed and therefore hotter. In the author's opinion, the nuisance value of flue gas is increased by washing it. If flue gas must be washed to remove sulphur dioxide, it would be wise to restrict the operation to stations in rural surroundings. Furthermore, unwashed gas discharged from high chimneys has an excellent chance of penetrating the ceiling of a fog and of thus passing harmlessly away, whereas washed gas must inevitably add to the fog.

R. LESSING, in discussion, said that before the war a process was devised for using the sludge from flue-gas washing for the production of pure calcium sulphate at gas-works ammonia scrubbers. Unfortunately, the work was interrupted by the war. He suggested that with such a plant the temperature of the exit gases would allow the gases to be dispersed by discharge at a height. The height could be estimated from plant experience. He agreed that a high chimney dispersed acid fumes satisfactorily, but pointed out that such a procedure might spread the damage, although avoiding it in the immediate vicinity of the works concerned.

A. WILSON drew attention to the lack of uniformity among local councils on the matter of permissible chimney heights. Such heights varied from 50 to 100 ft.

Dust Problems in Cement Manufacture

IN a paper on dust abatement in the cement industry, E. BURKE, J. J. L. MURRAY and K. R. JOHNSON said that the dust emitted at high level from cement manufacture consists in the main of chalk, clay and small amounts of coal ash and calcium sulphate. This is associated with large volumes of kiln gas containing about 35% by volume of steam, which, itself, accounts for the large white plume to be seen at the chimney tops of cement works. Electrostatic precipitators are widely used in the cement industry, the authors stated, and they described a number of new improvements in their design. These include:

(1) Fitting chutes at intervals along the main plate electrodes to reduce entrainment when the electrodes are rapped—a measure that helps to direct the dust positively to the hopper.

(2) Reducing the rate of rapping as much as possible to help the dust to form in sheets upon the plates. To reduce dust entrainment, stage working is being more widely used because it allows each section to operate at the optimum conditions.

Table, supplied by the authors, of costs of various methods of dust abatement used in the cement industry

	Efficiency on fine kiln dust*	Capital cost, £			Pressure drop, water gauge	Power cost, ‡ £ per annum	Maintenance repairs etc.,§ £ per annum	Total running cost,‖ £ per annum	Capital charges, £ per annum ¶	Total cost including capital charges			Overall equivalent pressure drop††
		Total†	per cu. ft. min.	per tons per hr. clinker						£ per annum	d. per 1,000 cu. ft.	per 1,000 tons of clinker	
Electrostatic precipitators (plate or tube)	97	60,000	0·60	3,000	0·4	2,400	600	3,000	6,000	9,000	0·042	53	12·0
High efficiency cyclones with fine dust shave off	77	31,000	0·31	1,550	3·3	2,700	200	2,900	3,100	6,000	0 028	35	8·0
Ditto, lower pressure drop	65	17,200	0·17	860	2·5	2,100	200	2,300	1,700	4,000	0·019	24	5·3
High efficiency cyclones with scrolled inlet	80	19,360	0·19	968	3·0	2,410	200	2,610	1,936	4,546	0·0214	27	6·1
Ditto, larger cyclones	75	17,700	0·18	885	3·0	2,410	200	2,610	1,770	4,380	0·0206	26	5·8
Tubular cyclones A	78	20,000	0·20	1,000	2·5	2,100	200	2,300	2,000	4,300	0·020	25	5·7
Tubular cyclones B + scraper gear	75	12,000	0·12	600	2·8	2,300	200	2,500	1,200	3,700	0·017	22	4·9
Ditto, higher pressure drop	75	10,500	0·11	525	4·0	3,300	200	3,500	1,050	4,550	0·021	27	6·1
Ditto, highest pressure drop	75	10,000	0·10	500	4·9	4,000	200	4,200	1,000	5,200	0·025	31	6·9
Cellular dust concentrator + secondary cyclones	60	11,500	0·12	170	1·9	2,100	200	2,300	1,150	3,450	0·016	20	4·6
Ditto, lower pressure drop	60	15,000	0·15	160	1·0	1,500	200	1,700	1,500	3,200	0·015	19	4·3

* Based on dust in Table 3.4.
† Includes foundations, lagging, extracting equipment, but not the fan.
‡ Includes extraction gear and fan efficiency of 60 per cent, electrical energy at 1·2 d. per kW-hr
§ Estimated.
‖ ‡ + §.
¶ Taken as 10% of capital cost.
†† Total annual cost expressed as power usage.

(3) Development of a tubular type of separator with a gas velocity of 30-40 ft per second. This separator uses a scavenging gas flow with a velocity of 100 ft per second to remove collected dust from the cell walls, and operates at 260-370°C with a pressure drop of 1 in. water gauge and with a power consumption of 20 kW per c.f.m.

(4) Automatic voltage control which temporarily reduces the voltage, if flashing should occur, to a point where stability is reached.

The authors suggest that there is still room for improvement of design; for example, the discharge electrodes should be made less vulnerable to vibration and should be easy to remove without using special tools; rapping gear and its lubrication can be improved; certain insulators should be lagged on the outside to prevent condensation; and dust-receiving parts should be made deeper. In the authors' opinion, the source of corrosion in the precipitator is in-leakage of air, which causes local temperatures to be set up lower than dew-point of the gases being treated.

In the discussion following this paper, C. J. STAIRMAND pointed out that, despite the high efficiency of small cyclones referred to in the paper, that kind of equipment had a special field. He and his co-workers had carried out experiments which showed that a cyclone with a 90.5% efficiency with a particular dust dropped in efficiency to 86.1% when a 5% base leakage took place; with 13% base leakage the efficiency dropped to 63.5%. If the cells choke uniformly, blockage is not a serious problem, because the increase in pressure drop will show what is happening. If the blockage is not uniform, gas will continue to enter the cells and will go out without dust discharge into the main body of the cyclone and choke the other cells. He had found that on a 16-cell unit a 90% efficiency was obtained when the equipment was clean. By blocking off the exit pipes of the cells in turn, they were able to see the effect of non-uniform blockage. With one cell blocked, the efficiency dropped to 89%, with two blocked it dropped to 61.5%, with four blocked to 24.5% and with eight blocked to 14.3%. During these tests little effect in pressure drop was noted, probably because it had been low in the first place. Mr. Stairmand thought that the idea of using detachable exit pipes might help, but long exit pipes were likely to cause more choking than short ones.

Electrostatic Precipitators

FOR improving the performance of power-station electrostatic precipitators, J. S. FORREST and H. J. LOWE, of the Central Electricity Authority's research laboratories, also advocated the automatic control of voltage to suit boiler conditions. A mechanical pre-collector, they said, is particularly valuable during lighting-up and soot-blowing when the dust burden is exceptionally heavy and coarse. It also reduces the emission in the event of a temporary precipitator failure. If placed immediately before the first treatment zone of a plate-type precipitator, the mechanical collectors—by virtue of the substantial pressure-drop in their use—can materially assist gas distribution. The authors believe that there is need for further information to establish the most suitable division of duty between the mechanical and electrostatic components. The chute type of electrode, designed recently to prevent the re-entrainment of deposited dust by the scouring action of the gas stream and during rapping, does not appear from the limited information so far available to be superior to tulip-type electrodes. Their performance, however, might be more favourable at higher gas velocities.

In discussion, Mr. STAIRMAND supported the authors' view on the combined cyclone plant. He had calculated the dust deposition adjacent to a power station, and his results indicated that with a combined plant 7% of the normal precipitation would take place, but with a combined plant of same capital cost as an electrostatic precipitator only 5% of the original deposition would occur.

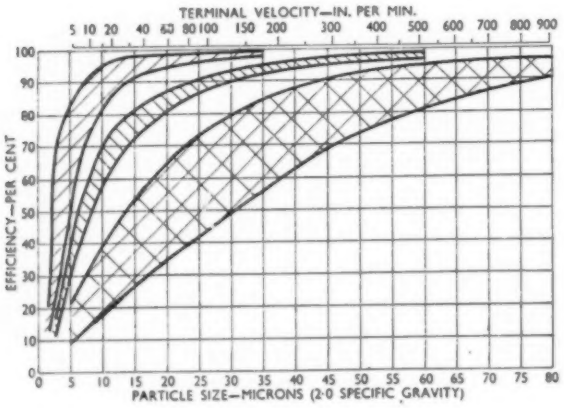
He doubted whether the authors would be able to achieve high drift velocities of 16 cm per second; if they could, it would mean a very important reduction in the size of the electrostatic precipitator plant, since size is governed by the reciprocal of the drift velocity.

H. D. TREVOR BUSBY stressed the need for uniform gas distribution at the entrance to an electrostatic precipitator. In his experience, the falling-off in performance arose through such causes as over-filling of hoppers, voltage settings too low, badly sealed doors giving in-leakage of air and, therefore, re-entrainment of dust. With the combined process, performance had fallen because of excessive gas volumes arising from poor combustion (low CO_2). Fine fly-ash had the advantage of reducing the effects of acids; for example, it helped to arrest corrosion.

J. W. PARTINGTON considered that the reason for higher efficiency in automatic voltage control was that the small amount of flashing provided a self-cleaning effect.

Mechanical Grit and Dust Collectors

TO help in estimating the performance of a particular mechanical grit and dust collector, J. C. JOHNSON and G. C. GOODWIN considered it worthwhile to define the term efficiency of these pieces of equipment. Knowing the efficiency with which particles of a particular size are collected, it is possible to plot a curve with efficiency as ordinate and terminal velocity as abscissa. In place of



High-efficiency multi-unit collectors.

Low-resistance multi-unit collectors.

Shunt-type collectors.

Graph showing efficiencies of mechanical grit collectors.

terminal velocity, particle size expressed as an equivalent sphere can be used. This will give what is known as a micron efficiency graph for a particular collector. The overall efficiency can be calculated from the grade efficiency of the collector and the grading curve of the dust.

The authors emphasised the need, often overlooked, for regular attention to the maintenance of separators, including the prevention of air in-leakage and choking, and the correct functioning of discharge valves. The lay-out of the plant should permit easy maintenance and ready sampling of gases entering and leaving the plant.

In discussion, W. F. CAREY commented that particles greater than 100 microns had escaped from cyclone separators, as could be seen from the efficiency curves. Failure to prevent contact between the cleaned air leaving the separator and that discharged at the base of the cyclone containing much dust causes observed efficiencies to fall below those expected theoretically. Cyclones are prone to this defect through the return flow up the centre core. He thought that static scroll collectors are not very effective on account of the torque they impose on the gases.

Instruments and Automatic Control

LEWELLYN YOUNG described a sampling system for flue gas which achieves a high rate of sampling with the use of a pump and which can deliver within 10 seconds a sample of gas to an analyser situated 25 ft away from the point of sampling. With a dry sampling tube the apparatus is suitable for working temperatures up to 600°F. A cooled sampling tube was also described that could be used in combustion chambers at temperatures of up to 2900°F. The author also gave details of a combustion meter containing anti-corrosion fatigue fittings, in which the primary element is a flow nozzle with elliptical inlet welded into the main. The upstream and downstream connections are arranged to return to the pipe and terminate each in an evaporating chamber which is in good metallic contact with the underside of the steam pipe, the volume of each evaporating chamber being greater than the total displacement of the flow meter. The condensed water which is displaced through the variations in flow and the consequent movement of the meter parts, is thus allowed time to evaporate and to approach the temperature of the steam before being ejected into the pipe.

Iron and Steel Industry

M. W. THRING and R. J. SARJANT *dealt* with dust and fume emissions from various kinds of furnace used in the iron and steel industry. In open-hearth furnaces the fume emitted contains from 0.5 to 2 grains of solids per cu. ft, with 50% of the particles of less than 5 micron and in some cases 50% less than 1 micron. For a 200-ton furnace, something like 25,000 cfm of gases require treatment. The only dedusters used for large-scale work are electrostatic precipitators and Pease-Anthony venturi scrubbers. One of the draw-backs of the electrostatic precipitator is that the gases must be cooled before they enter the equipment. A Pease-Anthony venturi plant, however, handles gases at 400°C, requires a pressure drop of 13 in. w.g., but cools the gases to 55°C so that they have little buoyancy at the top of the stack. Although the venturi scrubber is three times more costly to run than an electrostatic precipitator, the first cost of the scrubber is very much less and, since it is only in use intermittently, for example, during oxygen-lancing, there is some justification for its use. An alternative type of filter, at the development stage at present, is the continuous slag-wool filter. This apparatus operates with a pressure drop of 2 in. w.g. when cleaned, rising to 8 in. when dirty. The thickness of a filter element varies from ½ in. to 2 in. and gas velocity from 100 to 200 ft a minute. The filter has the advantage of being able to accept gases with a temperature as high as 650°C. Efficiencies of 85-95% have been obtained with pilot equipment.

Use of Smokeless Fuels

THE only paper which referred to the use of smokeless fuels was that by A. T. GREEN, on smoke emission in the ceramics industry. At present, under 10% of the firing-on of decoration was carried out in intermittently coal-fed kilns, he said. In the future, these would use either gas or smokeless solid fuel, and new designs of intermittent kilns fed by gas or by electricity were being developed.

USING AN AEROFOIL AS A MEANS OF FLOW MEASUREMENT

by C. E. R. SAMS, F.G.C.I., M.I.Mech.E.

The need for a method of measuring flow without serious pressure loss had a great deal to do with the evolution of the type of flowmeter herein described

THE experience at one particular waterworks, where the engineer's estimate of the cost of power lost annually in metering was around the £5000 mark, together with other and similar experiences, gave impetus to the search for a type of flowmeter less expensive in power. One such meter uses an aerofoil whose most important property, namely its lift, can also provide a means of measurement of the velocity of fluid flow. The lift of an aerofoil section in motion arises from the disturbance to the flow of air across its surface when it is in motion. When forced through an atmosphere, the surrounding air is accelerated at the upper surface of the aerofoil and decelerated along its lower surface. From Bernouillis' theorem, which can be stated simply by the equation:

$$p + \tfrac{1}{2}\varrho V^2 = \text{constant}$$

where p = static pressure, lb/ft²;
ϱ = density of medium, lb/ft² ÷ g; and
V = velocity, ft/sec.

it will be seen that at the surface adjacent to a zone of decreased air flow there must be an increase in pressure over that of the atmosphere and, conversely, at the zones of higher velocity there must be a reduction in pressure.

Pressure Differential

Hence, at the upper surface there is a negative pressure and at the lower surface, a positive one. The net result is an upward force on the aerofoil, given by the expression

$$L = C_L \cdot \frac{\varrho}{2} \cdot AV^2$$

where C_L = lift coefficient dimensionless;
A = projected area of wing section, ft.²;
V = velocity relative to the atmosphere; and
L = upward force in lb.

There is thus a connection between the pressure conditions at an aerofoil and its velocity through the atmosphere, which is, in essence, the underlying reason for suggesting that the aerofoil may be used as a flow-measuring device. It will be clear, therefore, that the difference between the pressure on the upper surface of a static aerofoil fixed in a pipe and the static pressure of the fluid flowing through it could conceivably be a measure of the fluid velocity. Fig. 1 shows the pressure distribution around an aerofoil in movement. Fig. 2 shows how some properties of wing

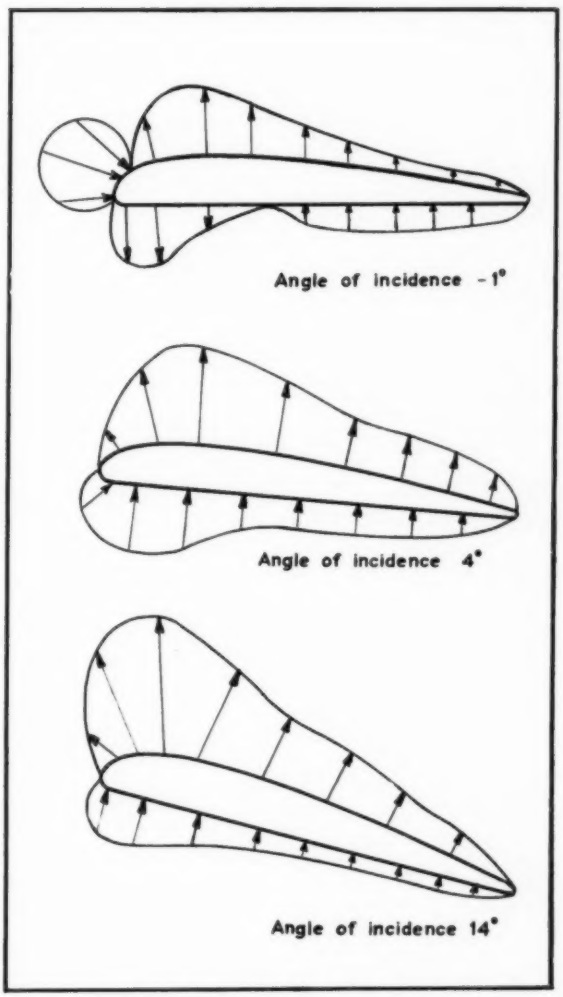


Fig. 1. Pressure distribution around the surface of an aerofoil in motion. On the cambered surface outward pointing arrows denote negative pressure; increase of angle of incidence up to a certain point increases the negative pressure.

employing a particular type of aerofoil (R.A.F. 38) vary with aspect ratio and angle of attack. The resistance to movement, or the drag, of a wing section is important, because if the aerofoil is used as a means of flow measurement it should not waste energy.

The following is a simple expression for power consumption for propelling a wing through an atmosphere at a velocity V ft/sec.

$$H.P. = \frac{C_D \, \frac{1}{2} \varrho \, AV^3}{550}$$

where C_D = drag coefficient dimensionless.

The foregoing points are essentially over-simplified theory. In fact, there are two theories of lift: that of Prandtl, which states that local lift depends upon free vortices formed downstream, and that of Jones, which postulates that lift is influenced only by flow ahead of a given point on the wing surface and is independent of the conditions downstream. Prandtl's theory applies to long wings, i.e., of high aspect ratio, whereas Jones' theory refers to low-aspect ratio wings.

Methods of Flow Measurement

Although there is an abundance of information on the aerodynamic properties of aerofoil sections, there is little or no data from which its behaviour as a flowmeter can be estimated. There is, however, enough knowledge of the aerofoil flowmeter to predict by analogy or interpolation and with fair accuracy its differential pressure for high rates of flow. In this respect, the aerofoil might appear to be at some disadvantage when compared with constrictive types of meter, such as the orifice and venturi. However, such comparisons are not altogether valid, since the equations relating flow rate to head loss include an experimentally determined discharge coefficient. A vast amount of data on the latter are available, especially from the work of the American Society of Mechanical Engineers Fluid Meter Committee, and, for this reason, the dimensions of a constriction for a particular duty can be estimated by formula. Looked at in this way, the aerofoil unit is perhaps at a minor and temporary disadvantage—one arising from its novelty.

Some of the widely used methods of flow measurement which depend upon differential pressure, such as the orifice and venturi meter, will next be considered. The rate of flow through either type of instrument can be obtained for the flow of a non-compressible fluid by equations of the type:

$$W = 0.525 \, KD^2 \sqrt{\varrho \, \Delta p}$$

where $K = \dfrac{C}{1-\beta^4}$;

β^2 = ratio of orifice cross-section to pipe cross-section upstream of the orifice;
W = lb. of fluid passing per sec.;
D = orifice drain, in.;
Δp = pressure drop, lb/ft²;
ϱ = density of fluid, lb/ft³; and
C = discharge coefficient for orifice.

With the orifice, the pressure differential is also a pressure loss in the fluid passing through the orifice, but with the venturi there is a considerable regain of pressure, so that the loss of pressure amounts to no more than 20%.

With instruments using discharge coefficients from accepted sources, an initial accuracy of 1% to 3% can be expected. Thus, for successful use of the orifice equation, an accurate value of the discharge coefficient is required. One difficulty here is that its value is susceptible to quite small upstream deviations from the conditions for which it applies. Strict adherence to installation specification is therefore necessary. The author recalls an experience illustrative of this point, which concerned a large venturi meter. This was designed to give a reading of 30 in. w.g. for a given rate of flow. Laboratory calibration at this flow rate gave a reading of 29.6 in., whereas at the plant the reading obtained was 29.2 in. Such discrepancies justify the view of the author that site calibration is a sounder method of obtaining the characteristics of a meter than by formula.

In the case of the constrictive type of meter, once it has been calibrated, a progressive loss of accuracy often takes place. This can be more or less severe depending upon fluid conditions. It can also arise from alterations in the pipe surface upstream of the constriction and at the constriction itself, through such agencies as corrosion, erosion and build-up. Another example of loss of accuracy is in the type of installation where a main flow is metered into a number of branches. Seldom does the main meter give a reading equal to the sum of the indicated rates of flow of the individual meters.

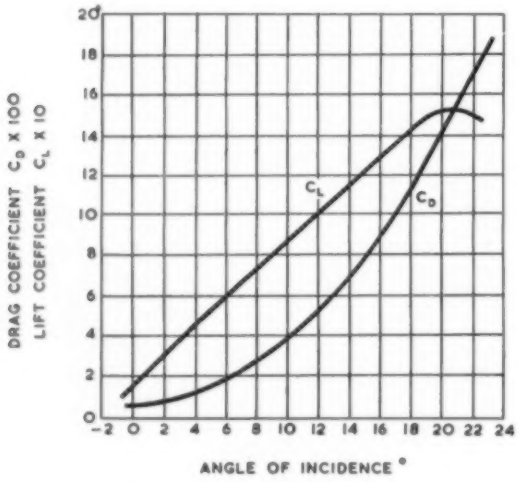


Fig. 2. Graph showing properties of wing using a particular type of aerofoil.

Meter Power Consumption

One can compare theoretically the power consumption required by the aerofoil and other types of differential meter. Let us assume that air is flowing at a mean velocity of 60 ft/sec. along a pipeline of 1 ft diameter and that the normal type of differential instrument indicates 4 in. w.g. at this flow rate. The projected area of the metering section will be assumed to be 1/10 that of the pipe cross-sectional area. If the aerofoil is an R.A.F. 38, angle of attack 4 degrees, then $C_D = 0.02$ (Fig. 2). From the power consumption formula the power loss in the air flowing over the aerofoil

$$= \frac{0.02 \times 0.0024 \times 0.08 \times 60^3}{2 \times 550}$$

$$= 7.5 \times 10^{-4} \text{ H.P.}$$

This figure does not take into account the drag due to the support. It will also vary for a given flow rate with the angle of attack and the type of aerofoil. Nevertheless, it does give an idea of the order of the power loss to be expected. The volumetric rate of flow in this example is 2830 cfm. The H.P. required by the orifice for a 4-in. w.g. reading

$$= \frac{4 \times 5.2 \times 2830}{33{,}000} = 1.8 \text{ H.P.}$$

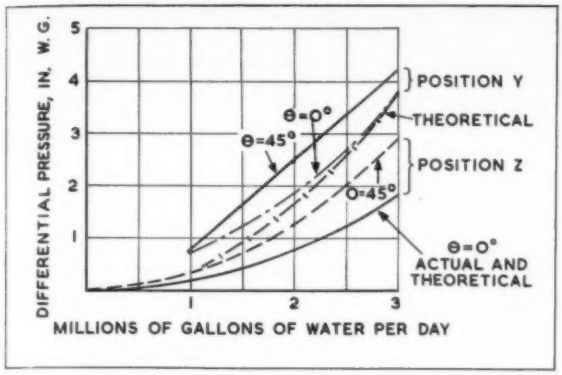


Figure 3a

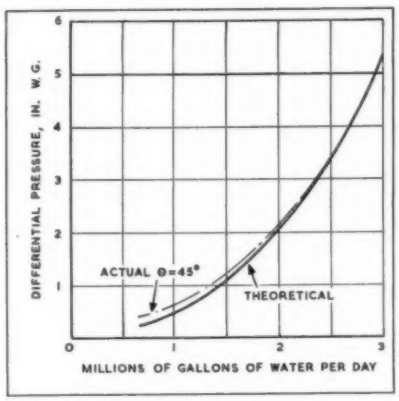


Figure 3b

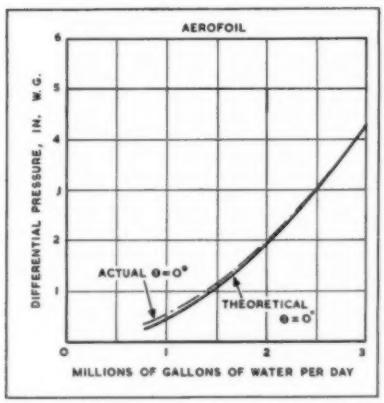


Figure 3c

Figs. 3a, 3b and 3c. Results obtained from an installation handling up to 3 million gpd of water in a 15-in. bore pipe.

A venturi with an 80% recovery of pressure would require 0.36 H.P. This theoretical advantage has been confirmed practically. Examples are provided by steam and water main installations where the differential meters required differentials of around 100, 60 and 20 in. w.g., whereas no measurable pressure loss occurred with the areofoil metering units fitted in these mains.

Some valuable results were obtained from a pipeline which carried a venturi, orifice, and tank-weir-hook-gauge instrument for reference purposes. The performance of the aerofoil was tested in this line and at various positions, e.g., after bends. The position of the aerofoil in the pipe was also varied, e.g., its angle of attack and its distance from the wall of the pipe.

Some Aerofoil Meter Results

Some of the results obtained from an installation which handled up to 3 million gpd of water in a pipe of 15-in. bore are shown in Figs. 3 (a), 3 (b) and 3 (c). Details of the installation and the method of varying the position of the aerofoil are shown in Fig. 5. It will be seen that the aerofoil, when fitted in a straight pipe-run of short length, gives a differential pressure approximating the square-root law; further increase of the angle of attack increases the differential pressure reading. By altering the position of the aerofoil relative to the tube wall, it is possible to make the reading follow the square-root law. This occurs when the position of the aerofoil is near the outer radius of the adjacent bend. Altering the angle of attack does not cause a deviation from the law but increases the magnitude of the differential pressure. When in a position near the inner side of the bend, the readings approximate to a linear law. Good reproducibility was obtained in the tests.

The results show that, unlike the normal differential meter, which requires a straight length upstream of the constriction and, sometimes, with flow straighteners for satisfactory performance, this provision is not at all necessary with the aerofoil, which can be located at any position in a pipe system. As mentioned earlier, calibration is necessary whatever type of installation is made.

Fig. 5 shows one method of constructing an aerofoil; this is mounted upon a tube which passes through it. The tube opening is faired in with the cambered surface. This passes through a flange which is bolted to a nozzle on the pipework. The static pressure tapping is also situated in the flange. This arrangement allows removal for cleaning or replacement of the unit. The alteration of angle does

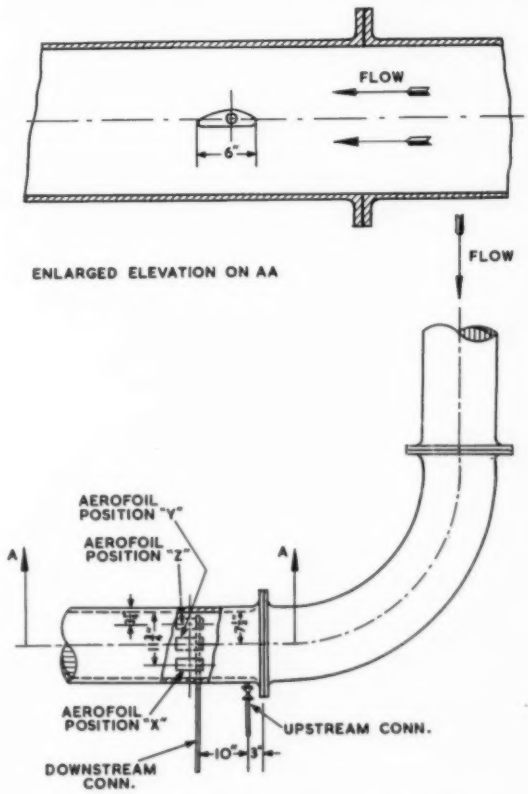


Fig. 4. Installation details and method of varying the position of the aerofoil.

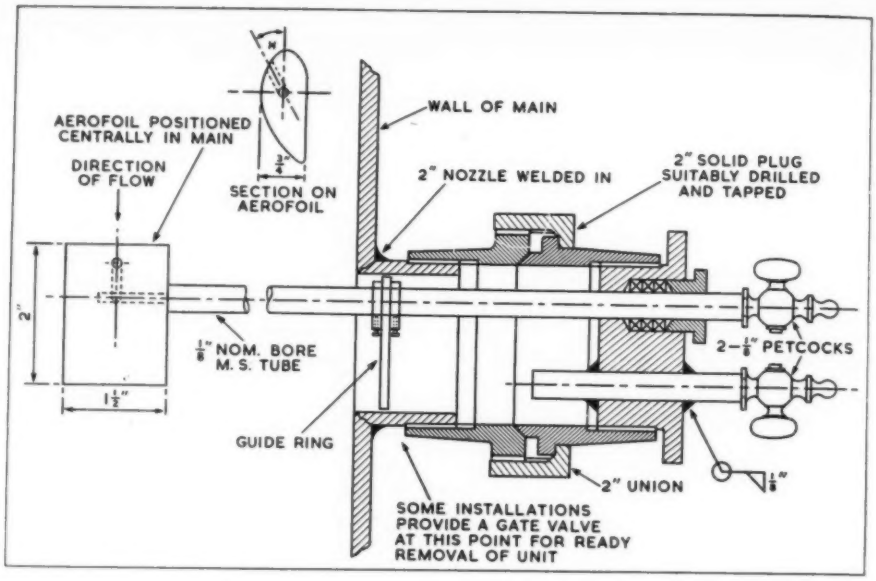

AEROFOIL POSITIONED CENTRALLY IN MAIN
DIRECTION OF FLOW
SECTION ON AEROFOIL
WALL OF MAIN
2" NOZZLE WELDED IN
2" SOLID PLUG SUITABLY DRILLED AND TAPPED
2"
1½"
⅛" NOM. BORE M. S. TUBE
2–⅛" PETCOCKS
GUIDE RING
2" UNION
SOME INSTALLATIONS PROVIDE A GATE VALVE AT THIS POINT FOR READY REMOVAL OF UNIT

Fig. 5. Diagram showing the constructional details of an aerofoil flow-meter unit.

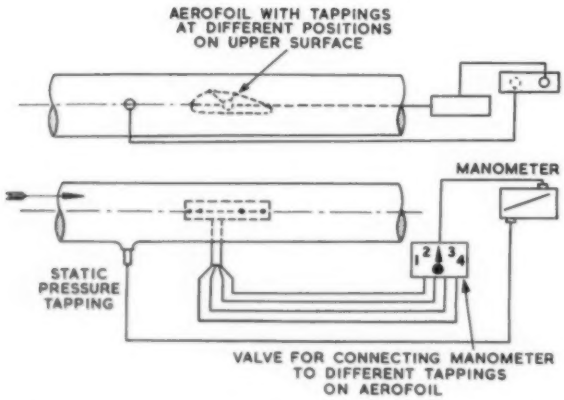

AEROFOIL WITH TAPPINGS AT DIFFERENT POSITIONS ON UPPER SURFACE
MANOMETER
STATIC PRESSURE TAPPING
1 2 3 4
VALVE FOR CONNECTING MANOMETER TO DIFFERENT TAPPINGS ON AEROFOIL

Fig. 6. A system of multiple tappings taken from different positions on the cambered surface of an aerofoil.

not require the removal of the unit, since rotation of the spindle through the desired angle is all that is necessary. One advantage of this arrangement is that the main pipeline need not be disturbed when such operations have to be carried out as it is possible to fit a gate valve in the branch carrying the meter connections. Normally, this will be open, but can be closed when the aerofoil section is withdrawn. This enables the unit to be removed without interrupting the process.

Aerofoil Advantages

The aerofoil unit may be constructed of almost any material, such as hardwood, glass, ceramics, plastics and any metal, covered or bare. Although this form of instrument is at present little used for corrosive conditions, the ease with which it can be made in resistant materials is a point in its favour, and one which should lead to its wider use for such purposes. Among its advantages over other differential instruments are the following:

(1) Independence of its differential pressure reading from the actual pressure loss in the fluid. Pressure losses are negligible.

(2) It can be installed in any position in a pipeline, including one immediately downstream of a right-angle bend. This advantage simplifies pipe layout and may allow the element to be placed closer to the flow recorder or indicator than might be possible with meters requiring a 20 to 30-pipe diameters straight length.

(3) Accuracy, once calibration has been carried out, is little affected by corrosion, erosion or by build-up in the pipe upstream of the element. This is in sharp contrast to the constriction meter, whose accuracy is particularly susceptible to such changes.

(4) Ease of dismantling enables ready cleaning and replacement. Adjustment to the amount of penetration across the pipe bore and angle of incidence, can be made by moving the spindle through the gland. Accuracy can be maintained over a wide range of measurements and for long periods.

(5) Existing meters based upon a constriction of flow are accurate down to 30% of the maximum flow rate to be measured. With the aerofoil, accuracy is maintained down to 1/70 of the maximum flow rate. This wide rangeability is obtained by altering separately, or in combination, the angle of incidence, the position of the aerofoil in the pipe and the orifice on the cambered section.

(6) For large installations, the cost of the unit is cheaper than orifice or venturi instruments and, moreover, the cost does not increase greatly with pipe diameter. It is possible, for example, to use a 2-in. chord section satisfactorily in a 30-in. pipeline.

(7) When installed after a bend, the unit may be made to follow either the square root or to approximate a linear law.

(8) When new conditions of flow arise, to retain sensitiveness, three methods of adjustment are available as indicated in Fig. 4. Fig. 6 shows a system of multiple tappings taken from different positions on the cambered surface of the aerofoil. These enable the point of negative pressure measurement to be varied at will.

(9) The aerofoil can be made in a variety of materials, such as titanium for high temperature applications, and can be rubber covered. The necessity, at the present state of understanding of the aerofoil flow meter, for site calibration by means of reference instrument or by a Pitot traverse, is a small disadvantage in comparison with its many advantages.

BASIC PRINCIPLES OF COOLING TOWER DESIGN

by DEREK J. TOW

B.Sc. (Eng.), Dipl.Chem.Eng.,

A.M.I.Mech.E., A.M.I.Chem.E.

Cooling towers are regarded both as fractionating columns and as heat exchangers. The design figures given herein relate to the mechanical-draught type, which is replacing the natural-draught type

IN considering a cooling tower as a fractionating column, it is found that the fundamental equilibrium equations of column design also apply to cooling towers. The basis of this method of designing is the determination of the number of times equilibrium is required to obtain a given performance, and this involves a procedure similar to that for determining the number of theoretical plates required. A theoretical plate of a cooling tower is the equivalent height of filling, in which the temperature of the air leaving the section is equal to the temperature of the water leaving. The height of filling equal to a theoretical plate will be found to vary from about 5 to 15 ft, depending upon the water concentration.

Analogy More Accurate

The fractionating column analogy is more accurate and more convenient than that of the heat exchanger, as the resulting equations do not involve an integration. It is the more straightforward and therefore offers less chance of error.

It has been found that the most effective water concentration in a cooling tower is between 2 and 3 gal./sq. ft. If the concentration is increased above this value, the performance falls off, and this is probably because less water surface is exposed to the air stream, as the water tends to form in globules rather than in droplets. If the water concentration falls below 2 gal./sq. ft, the water surface exposed to the air stream is again reduced because of the reduced quantity of water involved.

In designing a cooling tower on the fractionating column basis, the water concentration is fixed at approximately 2½ gal./sq. ft of ground area, and the air velocity at 350 ft/min. The height of the tower is then varied to achieve the required performance. The advantages claimed for this method are that the most effective water concentration is determined in advance and that, by varying the height to give the required performance, the tower is always operating at the point of maximum efficiency.

It has been found that the fundamental laws of heat exchange apply equally to cooling towers as to heat exchangers. However, the related equations become rather complicated because the two fluids, the water and the air, are not separated by a metal wall but are intimately mixed, and the water partially changes phase. The fundamental equations involve an integration which can only be solved by approximation. Therefore, they either become over-simplified because assumptions are made which are not necessarily justified, or they become so complicated as to be of doubtful value for purposes of design.

In a heat exchanger, the driving force producing cooling is the temperature differential between the two fluids, and there is, in effect, a temperature potential. However, in a cooling tower, the driving force is not the temperature potential; it is the difference in total heat, or enthalpy, between the air at its wet-bulb temperature and the air if its wet-bulb temperature were raised to that of the water. In cooling towers, then, there is an enthalpy potential as the driving force. It will be found that for the same temperature differential the enthalpy potential will be greater than the temperature potential. This means that the presence of the water on the air side increases the transfer rate.

In approaching the heat-exchanger problem, a number of variables, such as tube length, tube diameter, tube velocity and water quantity, are assumed to be constant, and the number of square feet of surface required is calculated to accomplish a given performance. In a cooling tower, a similar calculation is made. The effective height of the tower is fixed approximately at some convenient point, the air velocity at about 350 ft a minute, and the quantity of water over each sq. ft of tower ground-area is varied to accomplish the given performance. Then, when rating a cooling tower, the main job is to determine the water concentration that will be required for a given performance. Naturally the variation in performance with the water concentration has to be determined in advance experimentally.

Effect of Other Factors

The effect of wet-bulb temperature, ambient temperature, relative humidity, etc., on cooling tower design must be taken into consideration. The wet-bulb temperature is the temperature at which the air would normally saturate without any change in its heat content, and it represents the minimum temperature to which it is possible to cool water in an evaporative system. This temperature will vary with the time of day, the weather and the season of the year. Heat transfer in an evaporative cooling process is due principally to the latent heat effect of the evaporating water. The evaporation of 1 lb. of water, whether occurring in a steam boiler or a cooling tower, will absorb about 1100 Btu. Thus the evaporation of 1 lb. of water in a tower will cool 100 lb. of water through 11°. This provides a convenient means for estimating the evaporation loss.

In addition to the latent heat effect, there is also a small amount of heat transferred because of the temperature

differential between the water and the air. This may be either positive or negative, depending on the temperatures involved. On a very dry, hot day in the tropics, the ambient temperature (dry-bulb temperature) may be 10° or 15° above that of the water. On such a day, all the cooling must be done by the latent heat of evaporation, for the sensible heat would actually have a negative effect on the cooling.

All the heat lost by the water is absorbed by the air. This is evidenced by a rise in the total heat or enthalpy of the air as it passes through the tower. From this it can be seen that only those factors affecting the total heat will affect the tower performance. Since the total heat is determined by the wet-bulb temperature alone, cooling performance is independent of both the dry-bulb temperature and the dew point.

On commercial towers it is not possible either for the wet-bulb temperature of the exhaust air to equal that of the hot water, or for the cold water to be reduced to the wet-bulb temperature of the incoming air. However, the latter condition can be approached in very tall counter-flow cooling towers, as will be considered later, where the colder water contacts the coldest air and the hotter air contacts the hottest water.

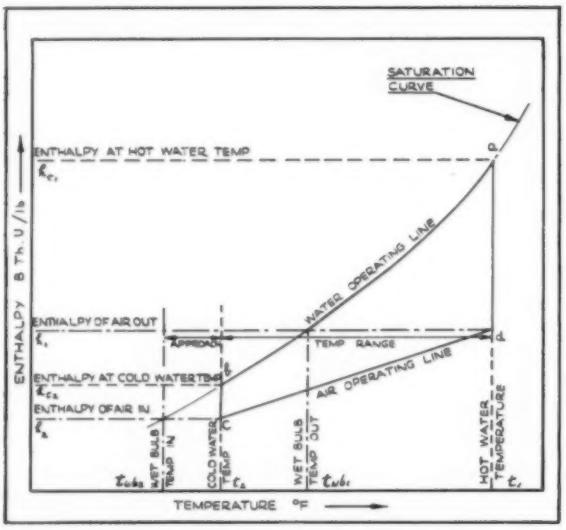


Fig. 1. Graph of the cooling process. The saturation curve shows the relationship between temperature and enthalpy of saturated air.

Cooling Tower Driving Force

A diagram of the cooling process is shown in Fig. 1. The saturation curve on this diagram shows the relationship between temperature and enthalpy of saturated air. This curve applies to the air film in contact with the water and becomes the water-operating line in the diagram, with its limits at the hot and cold water temperatures (t_1 and t_2), points *a* and *b*. Point *c* is the origin of the air-operating line, and is selected vertically below *b* at an enthalpy corresponding to that of the entering wet-bulb temperature (h_2). The vertical distance *b*-*c* represents the initial driving force or enthalpy potential. Point *d*, being the enthalpy of the air leaving the cooling tower (h_1), is on the air-operating line vertically below point *a*. The projected length of line *c*-*d* is the cooling range.

It should be noted that the co-ordinates of the diagram refer directly to the temperature and enthalpy of any point on the water-operating line *a*-*b*, but only to the enthalpy of a point on the air-operating line *c*-*d*. The corresponding wet-bulb temperature of any point on *c*-*d* is found by projecting the point horizontally to the saturation curve, and then vertically down to the temperature co-ordinate.

The position of *c*-*d* determines the approach to the wet-bulb temperature which is shown on the diagram by the horizontal distance between *c* and the saturation curve. An increase in wet-bulb temperature of the entering air, t_{wb_2}, moves the origin *c* upward and the line *c*-*d* moves to the right to establish equilibrium. The curvature of the saturation line causes the approach to decrease at a progressively slower rate as the wet-bulb temperature increases. A decrease in wet-bulb temperature has the opposite effect; point *c* moves downward and to the left and the approach increases at a progressively faster rate.

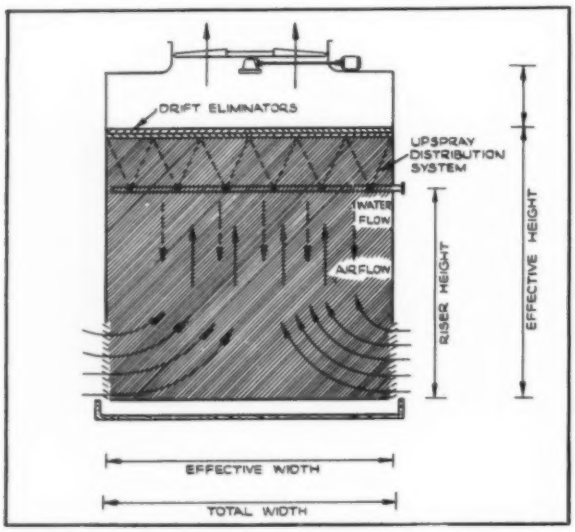


Fig. 2. Diagram of a tower operating to the true counter-flow principle in which the water remains in contact with the upward-sweeping air until it reaches the basin.

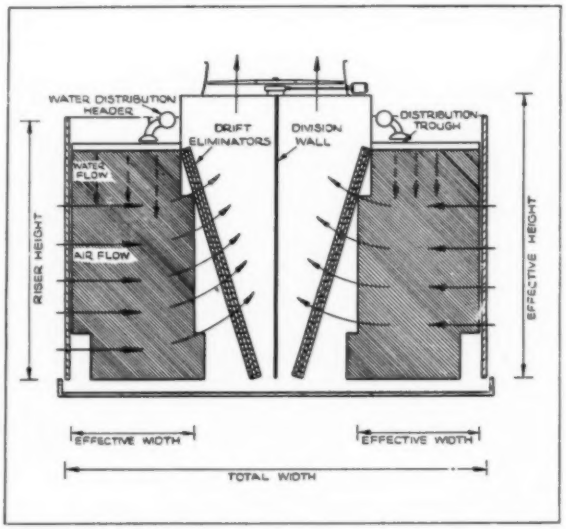


Fig. 3. An example of cross-flow cooling. The principle of operation is that of air traversing the water which falls vertically. Cross-flow is not as efficient as counter-flow cooling.

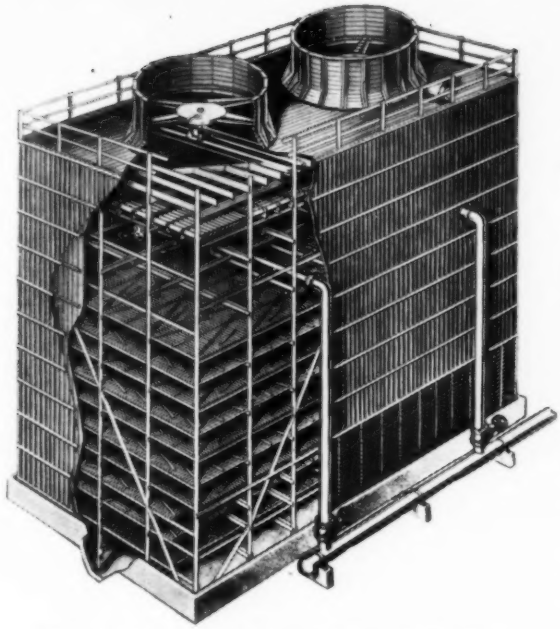


Fig. 4. Counter-flow induced-draught cooling tower. The advantage of this type of tower is that it requires a smaller basin for the same effective width.

All towers, whether of the natural or mechanical-draught type, operate with the water and air either in cross- or counter-flow. The following practical considerations are of importance in deciding which of these two main types of tower to select.

Important Practical Considerations

Principle of operation. In towers operating to the true counter-flow principle (Fig. 2), water remains in contact with the upward-sweeping air until it reaches the basin. Because of this long contact between air and water, the greatest possible use of the given amount of air is obtained. The water that is hottest, and therefore the easiest to cool, meets the most saturated air near the top of the tower, and at a lower level, the most difficult water to cool, the coldest water, contacts the least saturated air —the air with the greatest cooling capacity.

The cross-flow cooling tower (Fig. 3) operates on the principle of the air transversing the water which is falling vertically. Cross-flow cooling is not generally considered to be as efficient as counter-flow cooling, because the air is in only short contact with the water.

Utilistion of area. The effective height of a cross-flow cooling tower is usually quite low, and about 40% of the total width of the tower is ineffective for cooling. The velocity of the air passing through the air-intake louvres is usually between 350 and 400 ft/min., and this low air-velocity makes it very difficult to distribute the air. Performance is greatly affected by wind, and during high wind effective cooling is confined to the windward side of the tower. This tower arrangement is best suited for comparatively easy cooling duty. For more difficult applications, this equipment has not many advantages since it is only at the outer part of the tower that the colder water contacts the colder air. As the air passes farther into the tower the water approaches the temperature of the heated air rather than the temperature of the coldest air. This situation is analogous to the heat exchanger field, where a correction factor must be applied when cross-flow cooling is employed. The closer the cold water temperature approaches that of the wet-bulb, the greater the correction factor.

The advantage of the counterflow cooling tower (see Fig. 4) is that a smaller basin is required for the same effective width. More effective utilisation of the air is obtained in the counter-flow arrangement, and the adverse effect of wind on tower performance is greatly reduced.

Structural tower design. The general tower design should be investigated thoroughly before purchasing. The towers should be constructed for a wind loading of 30 lb./sq. ft even though the tower may never be subjected to this load, because a more rugged, durable structure is obtained (see Fig. 5).

Types of filling. In general, counter-current flow cooling towers incorporate sloping bar grid-decks which provide a maximum and continuous water break-up with a minimum obstruction to flow of the water. The design is usually arranged so that water cannot by-pass these grid-decks. Obstruction of air flow is held to a minimum, and the resulting low static pressure eliminates the danger of mis-alignment, warping, sagging and channelling. The grid-decks are strong enough to be used as scaffolding, yet they are sufficiently light in weight to be handled easily by one man. Counterflow packing is easily removed and each grid-deck is strong enough to be cleaned with a fire hose.

The filling of most cross-flow cooling towers is of horizontal and vertical lath-type members, interlocked. The fill is extremely thin, is not nailed and is not suitable to be used as scaffolding during the erection of a tower. It cannot be removed readily nor should it be cleaned with a fire hose. The efficiency of packing is affected by oil, dirt, algæ, and other foreign materials, and therefore the filling must be kept clean. A filling composed of flat horizontal slats collects foreign matter more readily than the decks composed of vertical or sloping slats. If the filling starts to sag the water becomes concentrated in the low areas. This, in turn, causes air channelling, since the

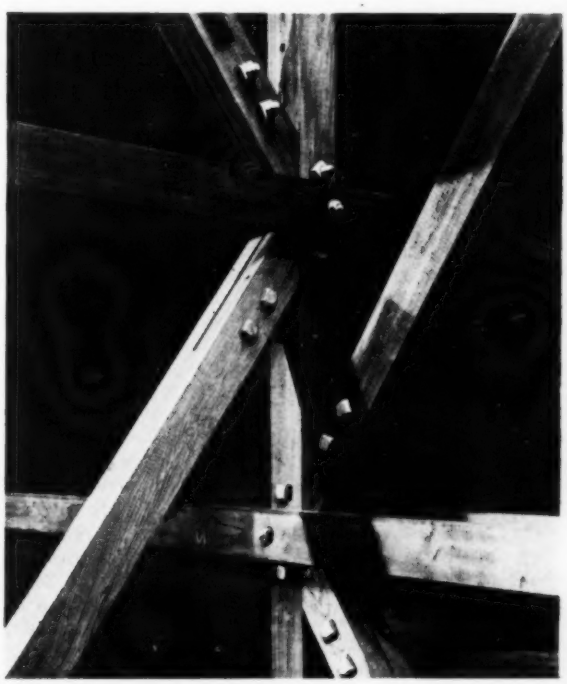


Fig. 5. The above illustration shows the types of jointing used in the construction of a counter-flow induced-draught cooling tower. Note the slots for gusset plates.

air will not pass as readily through areas of high water-concentration as through areas of low concentration, and air channelling lessens the contact between air and water, thereby reducing the preformance. The packing of cross-flow cooling towers tends to disintegrate after four or five years, due to its flimsy construction and its location in a horizontal plane which makes it extremely liable to attack by erosion and dirt or algæ.

Distribution Systems

The best type of distribution system is totally enclosed and gives a maximum initial water break-up and a uniform distribution over the entire plan area of each tower cell. The system operates under positive pressure. Being totally enclosed (see Fig. 6), the system is not exposed to sunlight and is protected therefore from air-borne debris. The water distribution deck and the drift eliminators are spaced to allow sufficient room for periodic inspections. Certain cooling-tower manufacturers using the distribution systems mentioned recommend cold-water temperatures to within 5° of the design wet-bulb temperature and, in some cases, less than 5°.

Some cooling towers include an open gravity distribution system. This system covers the effective part of the cooling tower roof, and a large number of small nozzles are used operating on an extremely low water-head. The system is not as flexible as the totally-enclosed type, because at high water-rate the tank tends to overflow, and at reduced water-rate the water is not uniformly distributed. The nozzles easily become plugged with small particles of debris, and the system is also susceptible to increased algæ growth, due to the hot water temperature and its exposure to direct sunlight. The tanks, therefore, require frequent cleaning and the whole water distribution system presents a continual maintenance problem.

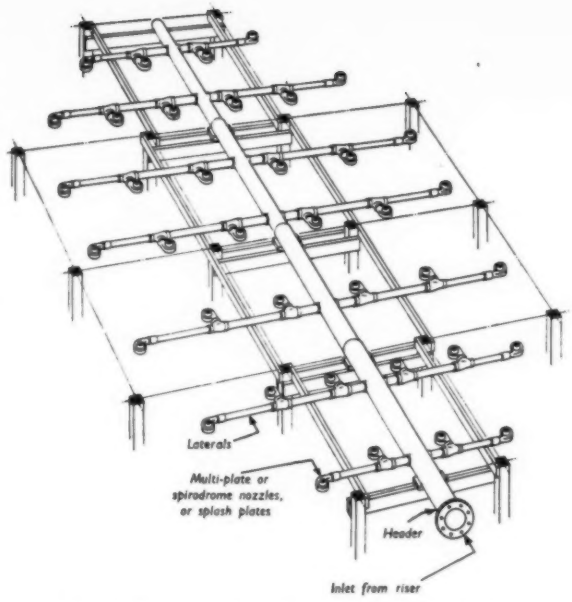


Fig. 6. Example of part of a water-distribution system for a cooling tower. The best type of water-distribution system is totally enclosed, giving the maximum water break-up.

Both from theoretical and practical considerations, the counter-flow type of cooling tower with a totally-enclosed distribution system is considered the more efficient.

A Modern Phosphorus Plant

THE Portishead phosphorus factory of Albright & Wilson has an annual capacity of 40 million lb. of phosphorus, a quantity greater than the total produced in the United Kingdom prior to the commissioning of the plant in 1954. In addition, the factory has been designed so that its output can be greatly increased at short notice.

The extraction process consists, essentially, of mixing calcium phosphate with silica and carbon in an A.C. electric-furnace. At high temperature, the silica displaces phosphoric oxide and forms calcium silicate, which is run off as liquid slag. The oxide is reduced by the carbon and the resultant phosphorus vapour and carbon monoxide are then passed over to a condenser, where they are separated. The carbon monoxide is used as a fuel in the calciners and boiler-house.

The principal raw materials used at the factory are phosphate rock and anthracite, which are brought to the plant by sea; and granite chippings, which are carried by rail. The phosphate rock and the anthracite are in a form which makes them suitable for handling by pneumatic plant, and they are unloaded by two mobile elevator gantries. The rock is stored in silos having a total capacity of 24,000 tons.

The first part of the processing of the materials is drying in the calciners. The materials are then automatically weighed and mixed, and the mix is carried by belt conveyors to hoppers at the top of the furnace house, from where it is fed, by gravity, into the furnaces.

The furnace house contains six electric reduction furnaces, each capable of a maximum loading of 7500 kW. The main shell of each furnace is fitted with a slightly arched roof, and the sides are lined with a refractory, and the base with carbon. The electrodes pass through the roof, which also carries the feed spouts and the offtake for the phosphorus vapour and carbon monoxide. Periodically, each furnace is tapped and the slag is run out into covered ways, where it is allowed to cool. Any fumes that may be emitted while tapping is in progress are extracted by fans mounted outside the furnace house at the base of tall chimneys into which the fumes are exhausted. The fans are driven by 100-h.p., 960-r.p.m., slip-ring induction motors.

The mixture of phosphorus vapour and carbon monoxide, which is continuously drawn off from the top of the furnaces, passes through dust extractors to the condensers. Here the phosphorus is cooled to the liquid state and the carbon monoxide is allowed to pass through for use as fuel. Transfer of the carbon monoxide from the condensers is effected by rotary boosters driven by 80-h.p., 1460-r.p.m. slip-ring induction motors. The liquid phosphorus is piped to heated underground tanks, where it is stored molten until it is pumped into specially constructed railway tank-wagons for transport to the manufacturer's factory at Kirby, near Liverpool.

The whole of the works electricity substation switchgear and metering equipment, distribution transformers, furnace transformers with the associated control gear and also a large number of motors, which provide 5000 h.p. for service in various parts of the factory, were supplied by the General Electric Co.

FLUIDISATION VELOCITY — STREAMLINE FLOW

The published data on fluidisation velocities have been critically reviewed by Johnson.[1] A mathematical analysis of his own experimental data led to the following equation for fluidising velocities in case of streamline flow:

$$u = \frac{g\,D_p^2}{18\eta}\,(\rho_s - \rho_f)\,\frac{\epsilon^5}{\{1+0.5\,(1-\epsilon)\}} \qquad \ldots . 1$$

The criterion for streamline flow is that the value of the modified Reynolds Number

$$\frac{D_p u\,\{\epsilon\rho_f + (1-\epsilon)\,\rho s\}}{\eta\,(1-\epsilon)}\,0.123\,\epsilon^2$$

is lower than 2. In general, however, it can be said that streamline flow prevails when a liquid is used as the fluidising medium.

This nomogram is a simple solution of Equation (1).

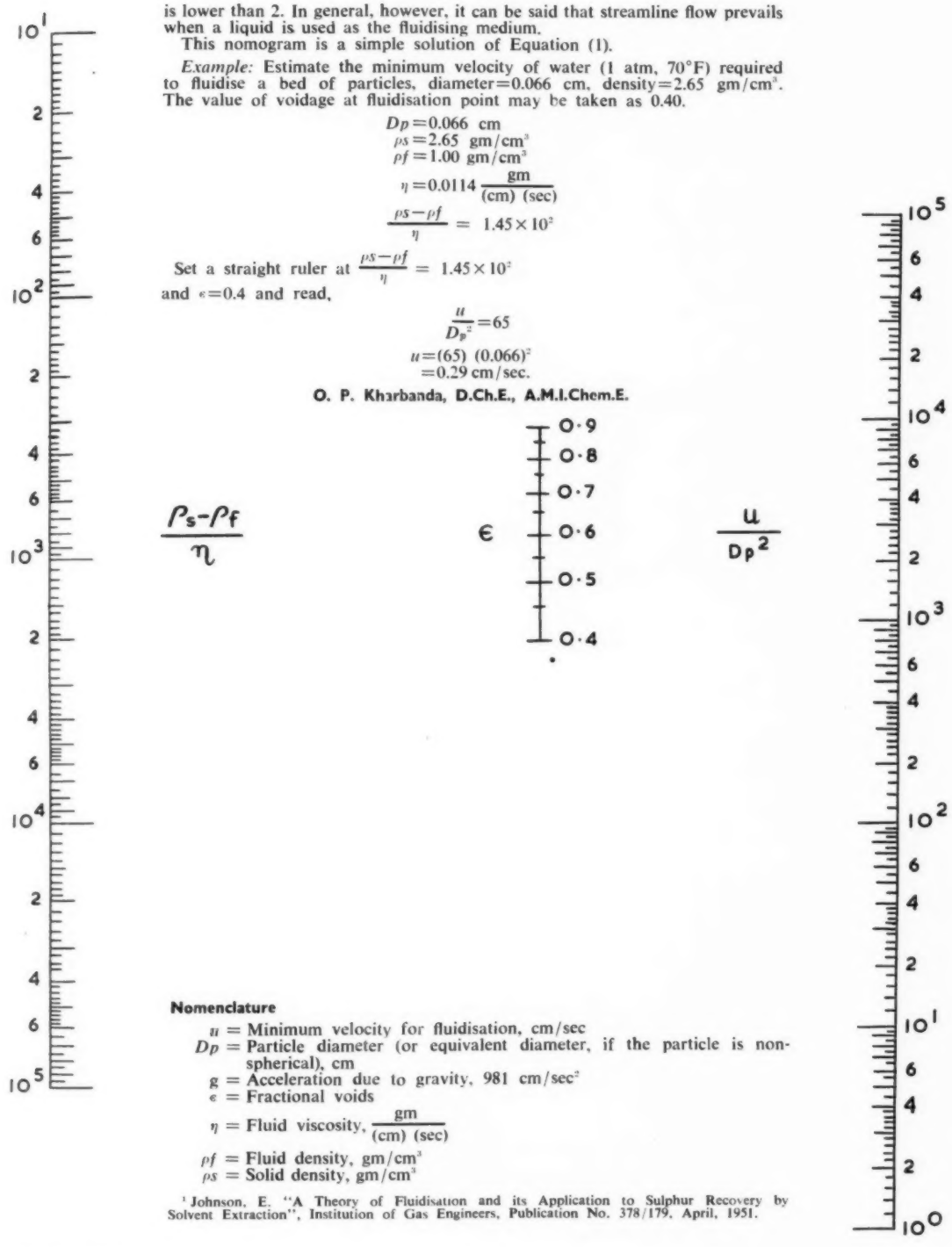
Example: Estimate the minimum velocity of water (1 atm, 70°F) required to fluidise a bed of particles, diameter=0.066 cm, density=2.65 gm/cm³. The value of voidage at fluidisation point may be taken as 0.40.

$$Dp = 0.066 \text{ cm}$$
$$\rho s = 2.65 \text{ gm/cm}^3$$
$$\rho f = 1.00 \text{ gm/cm}^3$$
$$\eta = 0.0114 \frac{\text{gm}}{\text{(cm) (sec)}}$$
$$\frac{\rho s - \rho f}{\eta} = 1.45 \times 10^2$$

Set a straight ruler at $\frac{\rho s - \rho f}{\eta} = 1.45 \times 10^2$ and $\epsilon = 0.4$ and read,

$$\frac{u}{D_p^2} = 65$$
$$u = (65)\,(0.066)^2$$
$$= 0.29 \text{ cm/sec.}$$

O. P. Kharbanda, D.Ch.E., A.M.I.Chem.E.



Nomenclature

u = Minimum velocity for fluidisation, cm/sec
Dp = Particle diameter (or equivalent diameter, if the particle is non-spherical), cm
g = Acceleration due to gravity, 981 cm/sec²
ϵ = Fractional voids
η = Fluid viscosity, $\frac{\text{gm}}{\text{(cm) (sec)}}$
ρf = Fluid density, gm/cm³
ρs = Solid density, gm/cm³

[1] Johnson, E. "A Theory of Fluidisation and its Application to Sulphur Recovery by Solvent Extraction", Institution of Gas Engineers, Publication No. 378/179, April, 1951.

AMERICAN LETTER

N-P-K by the Million Tons

MANY people think of American prosperity in terms of oil but the symbols N, P and K represent another vital portion of the nation's wealth. Without the nitrogen, phosphorus and potassium which the artificial fertiliser industry supplies, vast arable areas of the U.S.A. would be unable to support the growing population of the country. Fortunately, these essential elements can be obtained from indigenous sources, and reserves should be sufficient for many decades—in the case of nitrogen, of course, the supply is virtually inexhaustible.

According to the nature of the soil, the climate and crop requirements, an inorganic fertiliser may contain one or more of the elements N, P and K in amounts carefully proportioned to suit the specific need. In addition, special materials such as trace elements—manganese, cobalt, etc. —may be included in the formulation. In the western states of the U.S.A., fertilisers containing only one or two of the three primary elements are often used; for instance, anhydrous ammonia is now directly injected into the soil of certain wheat lands.

Reliance on Synthetic Ammonia

Over 90% of U.S. nitrogen demand is met by synthetic ammonia. For fertiliser purposes, ammonia may be applied directly to the soil, or it may be converted to numerous other forms, such as ammonium sulphate, ammonium nitrate, ammonium phosphate, urea, cyanamide, etc. For instance, out of a total of some 2,303,000 (short) tons of nitrogen supplied for fertiliser purposes in 1956, 460,000 tons (nearly 20%) were available as ammonia for direct application to the soil; 471,000 tons (20.5%) were converted to ammonium nitrate; 430,000 tons (18.6%) were fixed as ammoniated superphosphates and other mixed fertilisers; 352,000 tons (15.3%) were supplied as ammonium sulphate; and 293,000 tons (12.7%) were used to manufacture ammonium phosphates and nitrophosphates. According to the U.S. Department of Agriculture, the balance of 297,000 tons (12.9%) was available as natural organics, ammoniated materials and compound solutions, including aqua-ammonia.

In 1947 the nitrogen used by the fertiliser industry was about 920,000 tons, so that in less than a decade production for agricultural purposes has risen by 150%.

Since the fertiliser industry utilises about 70% of the nation's nitrogen supplies, the current total annual demand for all purposes is of the order of 3.3 million tons, which leaves a present surplus capacity of 21%. Even so, more synthetic ammonia plants are under construction, some of them being adjacent to agricultural areas; by the end of 1957 the total annual capacity should approach 5 million tons (of nitrogen). Even allowing for the growing population, the greater use of fertiliser *per capita* and increases in exports, it will be several years before the demand for synthetic ammonia equals the available production capacity, unless other large-scale uses can be found. At the same time, this ensures a plentiful supply of agricultural nitrogen and so should offer some protection against substantial price increases. Last year the price of anhydrous ammonia fell to about $70 per ton in some areas.

The chief source of phosphorus for fertiliser purposes is phosphate rock, which is mined in Florida, Tennessee and the western states of Idaho, Montana and Wyoming. In view of high transportation charges, it is usual to upgrade rock at the site of the mine before shipment to fertiliser plants in other parts of the country. For the same reason, considerable quantities of phosphate fertilisers are made in areas adjacent to the mines and are produced in the form of single-super, triple-super phosphate, ammonium phosphates and ammoniated super-phosphates. Some finely ground, upgraded rock is also shipped to certain areas for direct application to the soil. Compared to the spectacular growth of nitrogen consumption, the increased use of phosphorus compounds has not been great. Since 1947, consumption has risen by 31%. The total annual production for 1956 fertiliser purposes was 2,532,000 tons P_2O_5. Most phosphatic fertilisers are produced by wet-process methods, based upon reacting phosphate rock with sulphuric acid, as distinct from the electric furnace method which yields a purer, but more expensive phosphoric acid. About 80% of the wet-process acid made, and about 12% of all furnace acid, is used to make fertiliser compounds. As with synthetic ammonia, the current production capacity for phosphate fertilisers is greater than present demands, yet large new plants are under construction in such areas as Florida, Montana and Mississippi, in anticipation of future increased consumption.

The production of agricultural potash has expanded since 1947 at a rate which approaches the phenomenal increase of nitrogen fixation. It is estimated that nearly 2 million tons of potash (expressed as K_2O) were used in 1956 for fertiliser purposes, which represents an increase of about 125% over the 1947 figure.

Two Important Trends

The development of the American fertiliser industry cannot be told in terms of tonnages alone, however, for two major trends have been prominent during the last quarter of a century. The first is the increasing use of mixed fertilisers containing two or three primary constituents, and the second is the production of more highly concentrated fertilisers. Both result in reduced transport charges and costs of application to the soil.

The transition to more concentrated fertilisers, both mixed and unmixed, has been widespread, and on average the N, P and K total has risen from 13.9% in 1920 to 27.7% in the last year or so. As regards single-superphosphate, this material is giving place to triple-superphosphate; ten years ago, about 90% of the P_2O_5 applied as fertiliser was in the form of single-super, whereas in 1956 this figure had fallen to 62%. At the same time, the consumption of triple-super rose to 30%, and 8% was used in the form of ammonium phosphate and similar compounds. This is not surprising, since single-super contains about 18-20% available P_2O_5 and the triple-super contains 45-48% available P_2O_5. Mono-ammonium phosphate yields about 12% nitrogen and 52% P_2O_5 and di-ammonium phosphate is even richer, since it offers for commercial purposes about 18% nitrogen and 48% available P_2O_5. Hence, there is little doubt that the use of such highly concentrated fertilisers will continue to increase, now that manufacturing problems either from wet-process acid or gasworks liquors have largely been solved, since the advantages are many.

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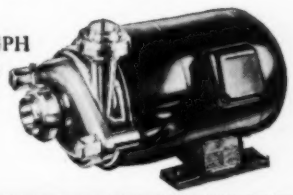

PROCESS ENGINEERING DIVISION

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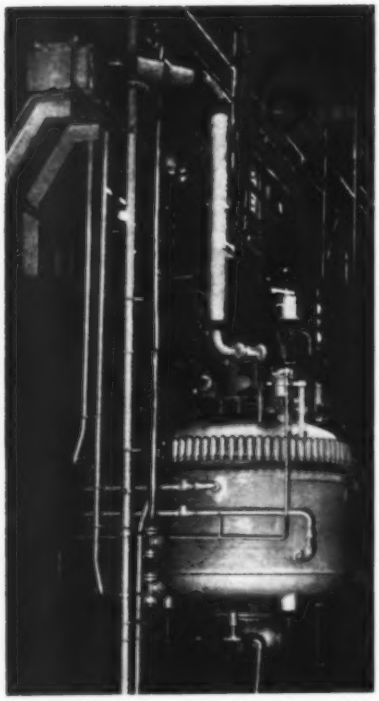
PROCESS ENGINEER'S NOTEBOOK

Heat Exchanger as Reflux Condenser

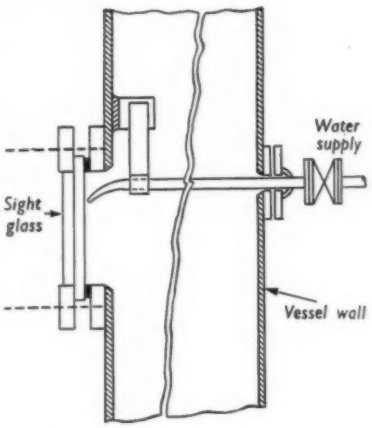


The graphite-block heat exchanger in use as a reflex condenser at the Poole Works of B.D.H.

GLASS-LINED reaction vessels for processing corrosive chemicals frequently employ reflux condensers also of glass-lined metal construction. Sometimes, however, the chemical manufacturer prefers all-glass condensers to the glass-lined type. Recently we visited a plant where neither type was being used, but, instead, graphite - block heat exchangers. An example of this unusual application is shown in the accompanying photograph taken at the Poole works of B.D.H. This is in use as a reflux condenser on a glass-lined vessel for the manufacture of a variety of chemical reagents derived from corrosive materials.

Sight Glasses for Process Vessels

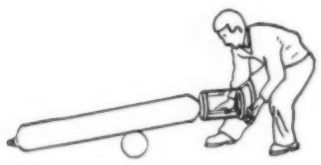
SIGHT GLASSES ARE USEFUL fittings on processing vessels so long as their interior surfaces can be kept clean. Occasionally they are fitted with mechanically operated cleaners resembling the earlier automobile windscreen wipers. Such devices are not always satisfactory and they cannot cope with hard crystalline deposits. A simple non - mechanical arrangement which has proved satisfactory is shown in the accompanying diagram. The idea is to direct a jet of water over the inner surface of the sight glass. It can be used in cases where the process taking place inside the vessel is not affected by the addition of a small quantity of water, as for example, when the process taking place is the evaporation or distillation of an aqueous solution.



Simple non-mechanical cleaning arrangement for sight glasses.

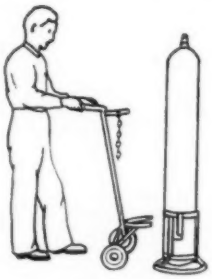
Novel, Cheap and Simple Transporter

A GROUP of engineers at the Ardeer factory of I.C.I. have devised a novel, cheap and simple transporter, resembling a golfing caddie-car, for the transport of cylinders, etc. It consists of two components, a cradle and a two-wheeled trolley. The diagram shows the operating principle and how the forks on the trolley part of the transporter are received by two clips fitted to the cradle. The cylinder to be handled is placed across a piece of wood, tubing or other support, allowing the cradle to be slipped over the lower end. The cylinder can now be placed upright and the forks of the mobile portion moved into position in readiness for transporting the cylinder. The operator, by a movement of the transporter handles, can raise the cradle clear of the floor in readiness for wheeling away. If one goes to the trouble of providing a number of supporting cradles, it simplifies removing the cylinders from filled cylinder storage to point of use and of returning them to the empty store.



Loading Nest.

Upending cylinder.



Entering fork lift.

Moving loaded cylinder.

Layout Designed for Continuous Sampling

THE LAYOUT shown in the accompanying diagram was designed to solve the problem of obtaining a representative sample from a pulp flowing to a filtration plant at the rate of about 2000 gpm. The amount of sample required had to be small enough to be handled conveniently, e.g., in a small receptacle such as a two-gallon bucket. In this arrangement pulp at the base of the sump flows into a centrifugal pump which keeps the pulp thoroughly mixed. The continuous fluid is taken from the pump discharge bucket to the sump. If the discharge is vertical, the sample may be drawn off on any convenient side of the pipe. With a horizontal-discharge line the sample pipe should be taken from the centre line of the main pipe when considering its vertical section. The sampler fixed above the sump traverses periodically the jet of pulp issuing from the bleed line, so that its scoop delivers a small quantity of pulp at intervals to the bucket. This arrangement gives very much better sample than one would obtain by intermittent sampling at some point from the main pump discharge line. With some types of traverse sampler, e.g., the Denver, it is possible to vary the sampling interval from 2 minutes to 1 hour by simply adjusting its timing mechanism.

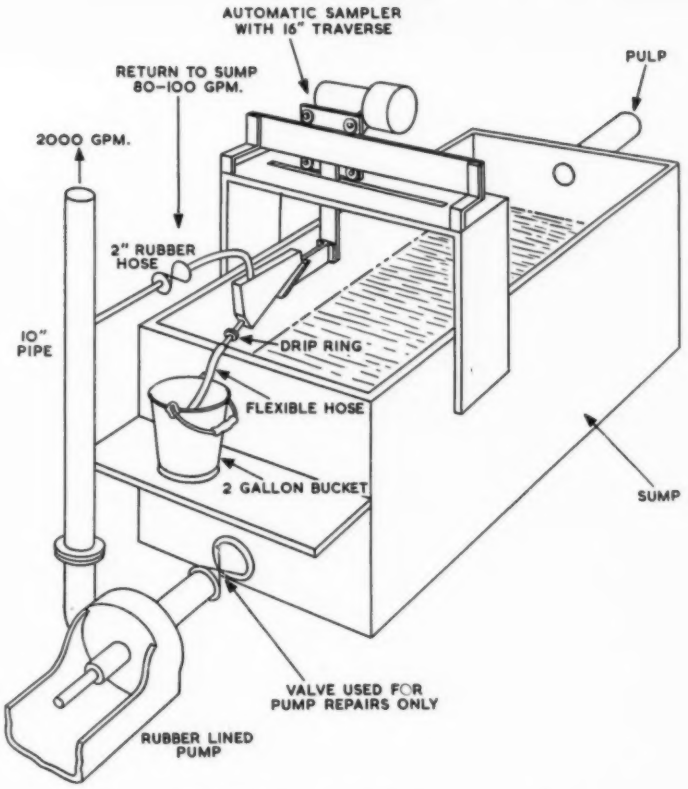
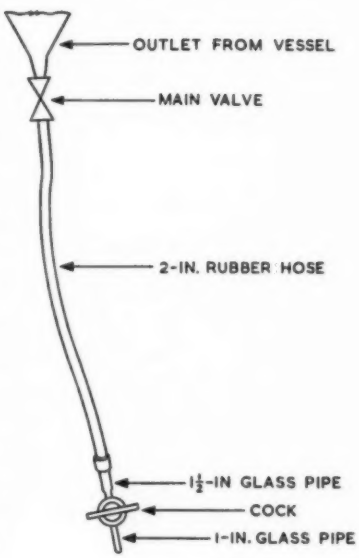


Diagram of the layout. This arrangement gives a very much better sample than that obtained by intermittent sampling at some point from the main pump discharge line.

Splash-prevention Device

THE ACCOMPANYING diagram shows a splash-prevention device to avoid disturbing a filter bed when filtering a liquor that is piped from a high head.

The valve of the container at, say, ceiling height is connected to a 2-in. rubber tube that leads towards the filter. Into the end of this tube is fitted a short length of 1½-in. glass pipeline terminating with a glass cock. From this is lead a stub of 1-in. pipeline. In use, the valve of the container is opened slightly, with the glass cock closed, and a little slurry passes down the tube as far as the cock. When the operator at the filter is satisfied that sufficient of the slurry is in the tubing he slowly opens the cock, so allowing the slurry to flow gently into the filter. He can keep a visual check of the flow of slurry from the main valve through the 1½-in. glass piping. The piping is connected to the rubber tube with a jubilee clip.



Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

Book Reviews

Fluidization

Edited by Donald F. Othmer

Reinhold, New York; Chapman & Hall, London; 1956, 231 pp., 56s.

THIS book is a symposium on various aspects of fluidisation by specialists in the field. Seven of the nine articles that it includes are by senior engineers of companies erecting and operating fluidisation plants.

The first two articles deal with the theoretical aspects of fluidisation; the second, dealing with heat and mass transfer, is a commendable review of work done in this field up to 1955. The third article presents a method of graphical expression of fluid-solid systems.

The remaining articles deal with practical applications and give a substantial amount of numerical data which are of great value in understanding and appreciating the mechanism and operation of industrial fluidised processes. Article 4 ("Background, History and Future of Fluidisation"), a contribution of the Esso Research & Engineering Co., is packed with useful practical data on particle sizes, gas velocities, bed expansion, entrainment and heat transfer, interspersed with comments on operation characteristics of interest to research workers. Article 5, presented by the Process Plants Division of Foster Wheeler Corporation, deals with operating problems and design factors for even gas distribution through the bed, solids flow in pipes, particle size control and solids recovery; it refers briefly to mechanical problems such as erosion and vibration.

Article 6 describes a particular application of fluidised bed processing, "Fluid Coking". The article is of general process interest and has no useful technical data relating to fluidisation as such. Article 7 is an article of general nature dealing with techniques of handling and controlling the flow of powdered or granulated solids, with a very brief treatment of reactor design. The Hyperflow solids transfer technique is described as employing a completely new phenomenon in solids handling, but in point of fact seems to be related to the old-established method of transportation using the Fuller-Kinyon pump. Article 8, by members of the Lummus Co., deals rather generally with the "Significance of Details in Cracking Units", but contains some useful figures on particle size distribution in good and poor beds, and entrainment losses. Article 9 deals very shortly with applications of fluidisation techniques in the chemical industry, as apart from petroleum processing, but unfortunately is limited to the field of roasting and calcining. Interesting operating data of a pyrites roaster are given, as well as information on a zinc sulphide roaster unit and multiple-compartment roasters for limestone. This article could well have been extended to cover a wider range of processing.

While its scope could have been widened with advantage, this volume contains sufficient information and references to warrant its place on the bookshelf of chemical engineers interested in the subject. N.J.H.

Heat Exchangers

by W. M. Kaye and A. L. London

Published by National Press, California, 1956, 156 pp., 40s.

THIS book presents an excellent compilation of the available data on heat transfer and fluid friction of the known varieties of extended heat-exchanger surfaces. Among the surface arrangements dealt with in the text are: plate-fin surfaces, nine varieties in all; fourteen kinds of louvred fin; three strip fins; five pin fins; six crimped regenerator matrices; and one sphere matrix, while, in addition, banks of bare tubes and flattened tubes are treated. The flow through dimpled and flattened tubes is also discussed. The surfaces described have a surface volume varying from 45 sq. ft to 2090 sq. ft per cu. ft of exchanger volume. This collection of information is considerably more voluminous than the last substantial treatment of the subject, made in the November 1945 Transactions of the A.S.M.E. Design data from this mass of information are easily extracted by means of very readable graphs which, incidentally, show the original test points upon which they are based. Although a lot of the data has already appeared in the literature an attempt had been made in the present book to iron out differences in treatment among the individual workers in the field. Further, in selecting parameters, such as the hydraulic diameter for use in the Reynolds No., the main object has been simplicity in order to ease the task of the designer rather than a generalised correlation. However, despite this, the clarity of the presentation should make the book valuable to those who wish to develop general correlations to cover a wide range of extended surfaces. The effect of various discontinuities, such as crimps and pins, are illustrated.

Perhaps the outstanding chapter is that dealing with design methods and basic theory. In this the reader is introduced to the relationship between exchanger effectiveness and the number of transfer units it provides. This approach, reminiscent of the theoretical transfer unit concept used in the analysis of diffusional processes, is useful for predicting the performance of a particular heat-exchanger unit. Graphs showing the exchanger effectiveness as a function of the number of transfer units are given for the usual cases of counter-flow, parallel-flow, cross-flow, with and without mixing, multi-pass cross-flow, and shell-and-tube arrangements. In addition, similar graphs are provided dealing with regenerative heat exchangers.

Analytical solutions for heat transfer in regular and circular tubes are described and the appendix includes three solutions to illustrate the use of the design data provided and the basic theory described. J.O.M.M.

High Pressure Technology

by E. W. Comings

McGraw-Hill, London, 1956, 572 pp., 86s. 6d.

UNTIL the publication of this book, the only other books on the subject were Bridgeman's "Physics of High Pressure", McMillan, London, 1931; Tongue's "The Design and Construction of High Pressure Chemical Plant", Chapman & Hall, London, 1934; and, latterly, Newitt's "Design of High Pressure Plant and Properties of Fluids at High Pressures", Oxford University Press, 1940. Only the last two are of commercial interest and, at the time of writing, are out of print. The appearance of this new volume, in which the author has set out to cover the entire field of high pressures, is therefore timely.

It seems a pity that over a quarter of the book has been devoted to the fundamentals of thermo-dynamics, chemical reaction kinetics and the traditional chemical engineering unit operations which have already been dealt with adequately in Dodge's "Chemical Engineering Thermodynamics", and in other books. On the other hand, a number of the problems likely to be encountered by the experimental worker in the field of high pressures are treated somewhat cursorily and qualitatively, although numerous references compensate for this short-coming. However, it is somewhat disappointing to find that the book does not provide a rational basis for the design of equipment for high-pressure duty. L.C.C.

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CHEMICAL PROCESS ECONOMICS IN PRACTICE

Edited by

J. James Hur

(Research & Development Dept., Atlantic Refining Co.)

120 pages *Illustrated* *32s. net*

This useful book records the proceedings of the fourth "Experience in Industry" Symposium jointly sponsored by the Philadelphia Wilmington Section of the American Institute of Chemical Engineers and the School of Engineering, University of Pensylvania. Nine experts in the economics of chemical process industries discuss, in a practical manner, many matters of particular interest to the industry.

37 ESSEX STREET, LONDON, W.C.2

World of Chemicals

Chemical Developments in Israel

A new factory for the production of carbide is to be set up near Petah Tiqva, Israel, using locally discovered deposits of lime. IL. 1 million is to be invested in the plant, two-thirds from local subscribers and the remainder from investors in Switzerland and the United Kingdom. The enterprise is scheduled to begin production before the end of 1957. Output is planned at 4000 tons a year, of which 1000 tons will be for export. Other developments in Israel include the reorganisation of the Dead Sea works which, during 1957, are expected to produce about 100,000 tons of potash. A laboratory for applied petro-chemical research has been set up at the Hebrew University in Jerusalem under the auspices of the Government, the United States Operations Mission and the Hebrew University.

Protection of Magnesium

A new electrolytic process for applying protective ceramic coatings to magnesium has been developed by Dow Chemical Co., Midland, Michigan, U.S.A. The process, it is claimed, will enable abrasion-resistant ceramic material to be bonded to magnesium metal parts more simply and more effectively than has previously been possible. It it said that the protective coatings can withstand temperatures of up to 650°C.

Indian DDT Factories

An agreement has been reached between Tata Chemicals and a United Kingdom firm for the manufacture of benzene hexachloride and other chemicals at Tata's Mithapur factory. The contract for supplying a DDT plant that is to be erected at Alwaye, in Kerala, has been secured by Singmaster & Breyer of New York. The factory, which will have a capacity of 1400 tons a year, is scheduled to be in production in 18 to 24 months' time, and it will be managed by Hindustan Insecticides (Private) Ltd., a Government-owned company.

Pharmaceuticals in Persia

With the aim of facilitating the control of the price and quality of pharmaceuticals in Persia, a decree has been published limiting the import of these products to the country. The foreign firms that are permitted to send pharmaceuticals to Persia have been reduced in number from 480 to about 100, but existing import permits, which are valid for up to three years, will continue in force until their expiry. Customs duty on pharmaceuticals is being reduced by 20%.

German Rubber and Phosphorus

The Badische Anilin- und Soda Fabrik (BASF) Ludwigshafen, Farbenfabriken Bayer, Leverkusen, and Farbwerke Hoechst, Frankfurt-am-Main (the three successor companies to the pre-war I.G. Farbenindustrie) have jointly established a company known as Synthesekautschuk-Beteiligungsgesellschaft m.b.H., with a capital of DM 60,000, to look after the interests of the three companies in the synthetic rubber manufacturing company, Bunawerk Huls, G.m.b.H.

Knapsack-Griesheim, Cologne, have raised their capacity for the production of yellow phosphorus to 35,000 tons annually. This will enable the company to meet all German requirements and, later, will produce an export surplus for sale to neighbouring countries.

Indian Sulphuric Acid

The present capacity for the production of sulphuric acid in India is 245,000 tons annually, and is provided by 37 plants. Authority has been given for the construction of another 14 plants which are expected to increase production by 240,000 tons annually. The target fixed for the end of the second five-year plan (1961) is 500,000 to 600,000 tons a year. A start was made recently on the fabrication of sulphuric acid plant in India.

Swiss Chemical Exports

During 1956 exports of chemicals from Switzerland rose, but not to the extent of the rise of total Swiss exports. Exports of dyestuffs in the first half of the year were 10% below the 1955 level, but the loss was more than made good in the second half. European markets took about three-fifths of the dyestuffs exports —slightly more than in 1955. The American share stayed about the same, but exports to Asia fell. Exports of pharmaceuticals in the first eleven months were 11% higher than in the same period of 1955. The home market received a particularly heavy demand for ebonite as a non-corrosive lining for vessels and other plant in the chemical industry.

Spanish Chemicals Industry

Provisional figures relating to industrial production in Spain during 1956 have been issued by the Minister of Industry. Those relating to chemical products are shown in the table given below.

Commodity	Production (thousand tons)	Percentage increase or decrease over 1955
Potash	230	+18.0
Lead	58.75	− 4.0
Zinc	22.8	− 4.0
Aluminium	13.5	+32.0
Copper	8.86	− 9.0
Sulphur	50	+33.0
Nitrogenous fertilisers	226.1	+ 3.0
Calcium carbide	56	+18.5
Superphosphate of calcium	1575	+ 8.5
Sulphuric acid	918	+ 6.0
Caustic soda	116.5	+16.5
Petroleum products	3890	+13.0

Large Germanium Crystals

One of the largest single-crystal ingots of germanium ever produced was grown recently at the Wembley research laboratories of G.E.C. It is about 8 in. long and weighs 1200 gm., and was produced by an automatic growing process which involves the slow withdrawal of a rotating seed crystal from a pool of molten germanium. The company has developed the technique to the stage where, it is claimed, large crystals such as this can now be grown automatically with great consistency and uniformity. The ingot took six hours to grow and contains only one part in 20 million of impurities. Its value is about £650.

Madras Essence Factory

W. J. Bush have opened a new factory for producing non-alcoholic essences, liquid colours and perfumed compounds at Nellikuppam, Madras. The factory will trade under the name of W. J. Bush Products (Private) Ltd., and will use as much raw material as possible from Indian sources. In due course, the company will develop manufacturing plants to produce a variety of raw materials from starting materials purchased in India.

Chemicals in Finland

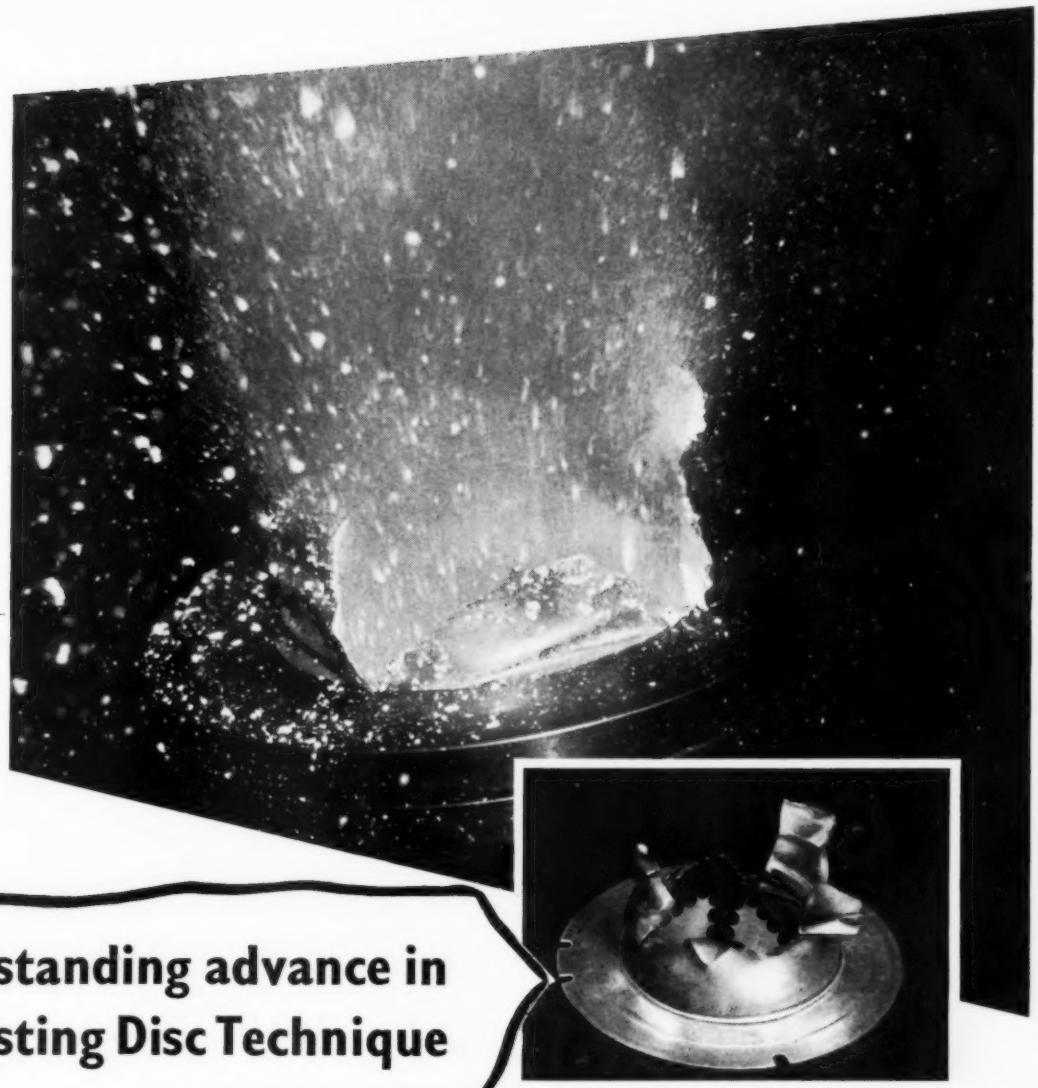
A new export from Finland during 1956 was vanadium, of which 67.5 tons were sold abroad. The present capacity of the Otanmaki plant is 300 tons a year, but, later, this will be doubled. The Federation of Finnish Industries reports that the chemical industry complains of being hampered during the year by lack of licences for machinery.

Gibberellic Acid Supplies

Small quantities of gibberellic acid (see *British Chemical Engineering*, April 1957, p. 176) are now being offered by Pfizer, Kent, to research workers interested in plant-growth stimulators.

Turkish Cement Furnaces

The second furnace of the Ankara cement works has been brought into use for a trial period. The first furnace produced 48,000 tons during its trial run of 5½ months, and the two new furnaces together should bring the production of cement in Turkey up to 1,230,000 tons a year.



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PLANT EQUIPMENT NEWS

Automatic Flaw Testing

Automatic inspection of materials of construction with ultrasonics is made possible by the use of apparatus being produced by Kelvin Hughes. The technique, which Kelvin Hughes have termed Autosonics, involves a combination of electronics and mechanics. In its simplest form, the process is to scan the material under inspection with a probe which transmits sound into the material as a sequence of energy pulses. These, in turn, are reflected from the opposite face and are received by the probe. The cycle of events is displayed as a trace on a cathode-ray tube and it may be recorded electrically on paper. The technique involves the use of a series of sensitive and stable electronic circuits which maintain constant vigilance and operate automatic alarms when defects are found. The inspection may be carried out at high speed. The electronic circuits on which the process is based comprise the following sections: flaw detection; automatic gain control; automatic flaw alarm and recording; and system fault alarm. After an initial setting-up procedure, these sections, it is said, replace the work of an operator, and perform his functions with speed, certainty and accuracy. So that the wide variety of requirements which will be encountered in manufacturing this plant may be dealt with adequately, the makers have considerably enlarged their factory. **Kelvin & Hughes (Industrial) Ltd., 2, Caxton Street, London, S.W.1.**

BCE 1229 for further information

An Electronic Air Filter

The Trion electronic air filter is being manufactured and marketed in the U.K. by W. C. Holmes, who are handling industrial applications, and by Harris Engineering, who are handling commercial uses. The filter is said to be capable of removing from the air particles less than 1/100 micron in diameter. The air to be filtered passes first through a high-voltage ionising screen which charges all of the particles positively. These are then attracted to the collecting plates, which form the negative elements of an electrostatic field set up between a series of parallel plates, charged alternately positively and negatively. The accumulated dirt from the air may be removed simply by flushing. The makers claim that the filter will produce sterile air for use in aseptic pharmaceutical processing and similar work. **W. C. Holmes & Co. Ltd., P.O. Box No. B.7, Turnbridge, Huddersfield; Harris Engineering Co. Ltd., York Works, Browning Street, London, S.E.17.**

BCE 1230 for further information

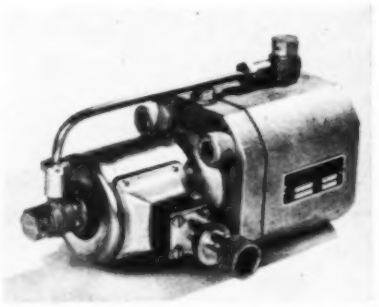
Plant to U.S. Design

As the result of an agreement concluded with the National Research Corporation, of Massachusetts, U.S.A., Wild-Barfield are now manufacturing equipment for vacuum melting, heat treatment and analysis, to N.R.C. design. The equipment includes arc furnaces with consumable or non-consumable electrodes, for the production of pure metals; induction furnaces of capacity from 12 to 3000 lb.; resistance furnaces for laboratory and research applications; and a hydrogen in titanium analyser. **Wild-Barfield Electric Furnaces Ltd., Otterspool Way, Watford By-Pass, Watford, Hertfordshire.**

BCE 1231 for further information

A New Solenoid Valve

A new solenoid two-way piloted piston-type valve for the control of chemically inert fluids or gases up to 1650 psi has been produced by Teddington Industrial Equipment. It can be made in sizes varying from ¼-in. to 2-in. bore and arranged to either open or close when energised. It has two main assemblies—the solenoid-operated pilot valve and the piston-type main valve unit. When the solenoid is energised the armature is

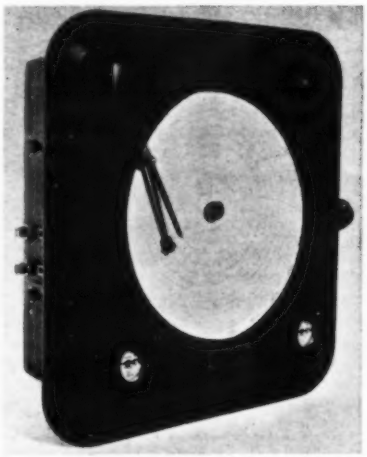


drawn up into the core and lifts the valve needle off its bottom seat. This relieves the pressure which has built up inside the piston through a bleed hole, by allowing it to escape to the outlet port, and, since the orifice of the needle valve is greater than that of the bleed hole, an out-of-balance pressure is exerted in an upwards direction, as the piston has a greater area than the main valve head. This upward thrust is sufficient to compress the piston-return spring and open the main valve. In the reverse-acting model the bottom port of the servo valve is blanked off and the top port connected to the main outlet. **Teddington Industrial Equipment Ltd., Sunbury-on-Thames, Middlesex.**

BCE 1232 for further information

Resistance Thermometers

Fieldens have produced a new range of electronic resistance thermometers, accurate to about 0.2%. They can be supplied for any range span greater than 20°C between −200°C and

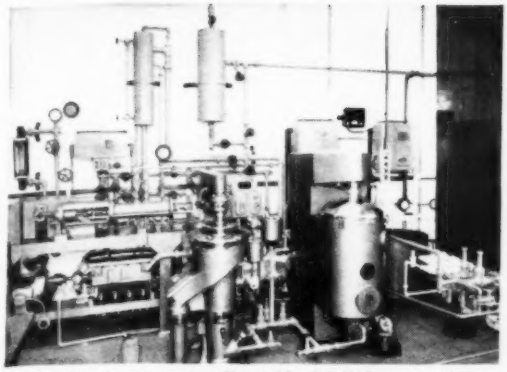


+500°C as single-point recorders and as four-point recorders. An additional indicating scale about eleven inches in diameter can also be fitted to the single-point model. Servo-power overcomes friction and provides the torque to operate electrical on/off controllers or pneumatic controllers. **Fielden Electronics Ltd., Wythenshawe, Manchester, 22.**

BCE 1233 for further information

Ultrasonic Cleaning

Dawe Instruments have introduced a new ultrasonic cleaning generator suitable for a wide range of requirements. The equipment consists of a self-contained generator, connected by cable to a transducer which converts the electrical impulses into mechanical vibration. One generator, using only about 250 watts of power, can drive one standard 1-gallon ultrasonic cleaning tank or two standard ½-gallon tanks with built-in transducers. Cleaning is carried out by immersing the components in the solvent normally used for manual cleaning. The process is speedy, and even grease rubbed into the teeth of a smooth file is completely removed, it is claimed, in about 20 seconds. The transducers can be



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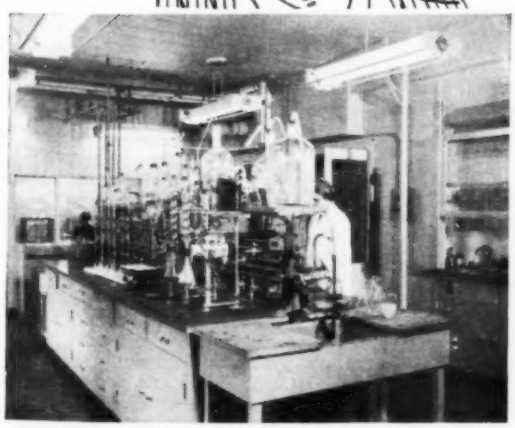

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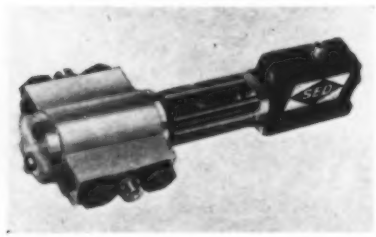
PLANT EQUIPMENT NEWS

operated in baths kept at temperatures of up to 170°F. Immersible transducers are also available to convert existing tanks into ultrasonic cleaning installations. **Dawe Instruments Ltd., 99 Uxbridge Road, London, W.5.**

BCE 1234 for further information

Air-operated Pumps

SED Engineering are producing a range of Neumo air-operated pumps which are constructed with no metal-to-metal sliding contact. They are energised by the standard Neumo motor, which itself has only two solid moving parts—a feature that makes for reliability, low cost and high efficiency. The design also results in a pumping unit which will raise a hydraulic system to a given pressure and then stall, only restarting when pressure in the system drops. The pump is of a double-acting plunger type, has disc valves and enables liquids to be raised to a con-



siderable head of pressure. Standard pumps are constructed of cast iron, and a choice of material for plunger and gland of leather and plastics, including PTFE, is given. The pumps may be made of other materials to order, and the manufacturers are proposing to market in May a pump made entirely of PTFE for handling very reactive liquids. The simple design of the pumps, it is stated, helps their cost to be kept low. **Kingsbourne Products Ltd., 216a South Coast Road, Peacehaven, Sussex.**

BCE 1235 for further information

Gas Turbine Equipment

Standard Motors have been developing a range of gas turbines for some time and will shortly start production of a 250-h.p. unit. It has been designed for use with stationary units where continuous running is desired or where mobility is essential. The unit will be marketed by **Auto Diesels Ltd., Uxbridge, Middlesex.**

BCE 1236 for further information

An Automatic Weigher

An automatic weigher and filler designed specially to handle sticky powders and granules in fillings of from 2 oz. to 16 lb. is being made available by Alexandra Separator. It employs a 1 : 1 true-beam balance with standard weights and has a control system which makes the best use of main and dribble feeds according to the nature of the product being handled. The product is moved by electrical vibrators applied to the feed hopper, the discharge chute and spout. The machine can be switched at will for automatic or semi-automatic working. **The Alexandra Separator Co. Ltd., 27 Pancras Road, London, N.W.1.**

BCE 1237 for further information

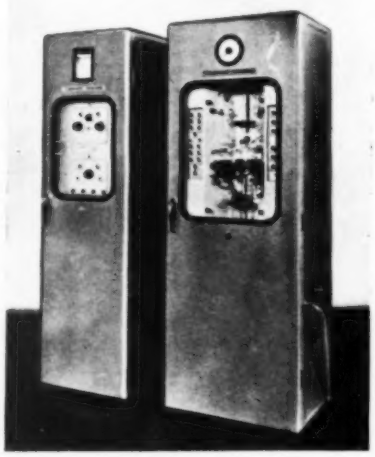
Automatic Tap Changer

Claude Lyons have developed an automatic electronic tap-changing transformer designed so that the output voltage always remains within ±5% of the declared value, for input changes of as much as −20% to +10%. The instrument, the ATC, is a development of the company's a.c. automatic voltage step-regulator. It is made in two sizes, rated at 2½ and 5 amps when the voltage is 200-250, and both have the advantages of being small and light. **Claude Lyons Ltd., Valley Works, Ware Road, Hoddesdon, Hertfordshire.**

BCE 1238 for further information

Automatic Analysis

The Titromatic analyser, an automatic titration apparatus developed by Electronic Instruments in conjunction with the Billingham Division of I.C.I., has been designed to undertake continuous analysis of chemical processes. It is connected to the main plant-stream, and at regular intervals a measured quantity of the solution being manufactured is fed to the reaction vessel of the instrument. After the sample has been diluted with water, titration with a standard reagent begins. The amount of reagent used for neutralisation is determined by an "electric eye", which finds the level of the reagent and records the volume used on a recorder chart. In the meantime, the reaction vessel is being emptied, and the



whole process starts again. The analyser consists of a chemical unit, which contains a series of glass vessels controlled by automatically-operated taps, and an electronic control unit, which determines the sequence of operations performed by the chemical unit. The time cycle of a titration can be varied from once every three minutes to once every half an hour, and the instrument is intended to operate day and night without attention. The visual record enables variations in the the plant-stream to be detected instantly and corrective measures to be applied. The apparatus is believed to be the only one of its type in existence. **Electronic Instruments Ltd., Lower Mortlake Road, Richmond, Surrey.**

BCE 1239 for further information

Tank of Laminated Plastics

The first large structure in which Bakelite resins have been used as a material of construction was erected

recently for The Ever Ready Co. It consists of a tank 8 ft × 4 ft × 6 ft on a stand 10 ft high, built throughout of laminates of Bakelite epoxide and polyester resins, reinforced with glass fibre. The stand is described as a "properly stressed engineering structure", and the rigidity of its main supports is enhanced by the use of cross-members. The tank has been designed for the storage of zinc chloride and, when full, weighs 10 tons. **Mendip (Chemical Engineering) Ltd., Feltham Road, Ashford, Middlesex.**

BCE 1240 for further information

Experimental Equipment

Alfred Bullows now have an experimental gas-turbine-driven compressor set for development work. The power unit is the Rover IS/60 gas turbine engine with an output of 60 b.h.p., and the compressor is the R4000 series Hydrovane sliding-vane rotary unit. The turbine runs at 46,000 r.p.m. and an integral gearbox reduces this to 3000 r.p.m. at the take-off shaft. Bleed-off air at 3 atmospheres is taken from the centrifugal compressor of the gas turbine and, after cooling, is fed to the compressor, which, in turn, compresses it to 100 lb./sq. in. gauge pressure. At this pressure the air compressor will deliver approximately 300 c.f.m. At present the assembly merely consists of the engine and compressor; its total weight, however, is only about 500 lb. No attempt has yet been made to investigate commercial applications,

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The Cambridge Model DE Electronic Recorder measures any quantity that can be converted into a small current or voltage. It forms an integral part of complete Cambridge equipments for the measurement of temperature (thermocouples, radiation pyrometers, resistance thermometers), gas analysis (katharometer bridge method), determination of pH values, dissolved oxygen in boiler feed water, etc.

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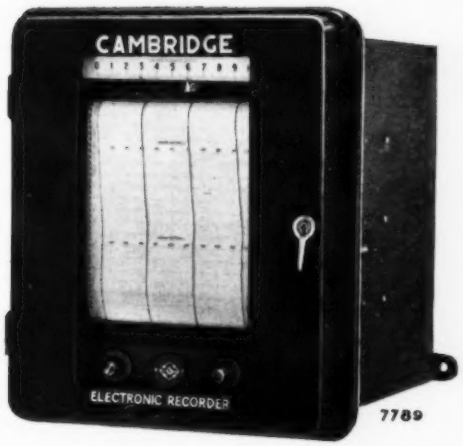

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permit inspection but protect against damage.

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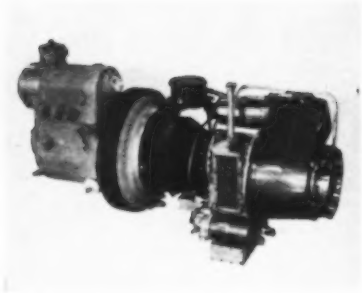
BCE 1185 for further information

NEW EQUIPMENT SEEN AT THE O.C.C.A. NINTH TECHNICAL EXHIBITION



but the makers say there are many applications where the light weight and easy maintenance of a unit of this type would offer outstanding benefits. **Alfred Bullows & Sons Ltd., Long Street, Walsall, Staffordshire.**

BCE 1241 for further information

Other Items of Interest

Gosheron have developed a pipe-wrapping machine for use with Vylap No. 9 P.V.C. pipe-wrapping tape. It will wrap any length of pipe of any diameter up to 3 in. The company is also marketing for banding, sealing and tying Twistseal, a cellulose film into which has been bonded fine strands of steel wire. It is cut into desired lengths with a dispenser. **John Gosheron & Co. Ltd., Albert Embankment, Vauxhall, London, S.E.11.**

BCE 1242 for further information

Metal-clad polythene drums are being made by Ward-Adams. Known as Waco drums, they consist of two containers—an inner polythene drum moulded in one piece and fitted with a screw cap centrally in the top; and an outer steel shell to withstand hard handling. The two parts are built to function as one unit. **Ward-Adams Co., 25 Hart Wood, Sevenoaks, Kent.**

BCE 1243 for further information

A new type of multi-wall paper sack has been designed by William Palfrey specially for the carriage of Nitra-Shell, a new granular nitrogenous fertiliser. The problem of excluding moisture from the fertiliser during transport and storage has been solved by the use of a five-ply paper sack, which includes one ply lined with polyethylene and one ply lined with bitumen. **William Palfrey Ltd., 24 City Road, London, E.C.1.**

BCE 1244 for further information

Mark-o-Print have added to their range of marking machines the Auto Rollmaster Junior. The model, which has a standard printing area ¾ in. wide, is used for the coding of bags or sacks of paper or hessian, travelling on a conveyor. **Mark-o-Print Ltd., Station Path, Putney Bridge Station, Fulham, London, S.W.6.**

BCE 1245 for further information

An electrolytic polisher for use in the preparation of metallographic specimens prior to etching and examination under the microscope has been introduced by **Nash & Thompson Ltd., Oakcroft Road, Chessington, Surrey.**

BCE 1246 for further information

Modifications to Mixer

Modifications have been made to the Ultramix high-speed mixing and dispersing machine introduced by Vickers last year. The ports have been opened out by redesigning the fixing of the rods to the spider; a sealed bearing has been installed below the motor, and a draught deflector has been incorporated in the motor housing to prevent draughts from the power source disturbing light powders under process. For greater convenience in handling, the shackle has been split so that it may swivel. **Vickers-Armstrongs (Engineers) Ltd., Vickers House, Broadway, London, S.W.1.**

BCE 1247 for further information

Continuous Batch Mixing Plant

Holmes Brothers announce that patents are pending for an automatic continuous-batch paint-making plant which they have designed. The plant is controlled by a series of interlocks. **Holmes Brothers Paint Machinery Ltd., 38 Victoria Street, London, S.W.1.**

BCE 1248 for further information

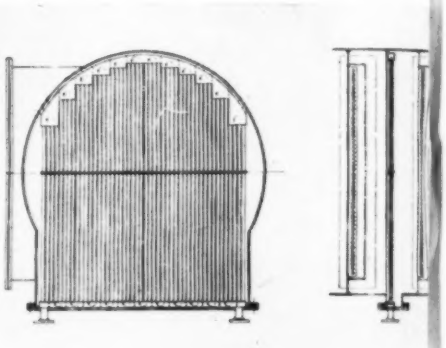
A Solvent-free Stopper

A new stopper that adheres to most surfaces without the use of a primer and that withstands stove enamelling has been marketed by Aero Research. The product, Araldite 880-AB, is supplied as two pure liquid resins, and therefore sets without the evaporation of any solvent. Curing takes place with negligible shrinkage, it is said, and is independent of the presence of oxygen. Stored separately under cool, dry conditions, the components can be kept for at least one year. **Aero Research Ltd., Duxford, Cambridge.**

BCE 1249 for further information

Heat and Mass Transfer Tray

A tubular distillation tray for conducting at once heat and mass transfer has just been made available by Metal Propellers. It is known as the Thermagrid and is a development of the Shell Turbogrid design of tray. Tubes replace the bars or slotted plates of the normal Turbogrid, and through them heating or cooling media can be passed to add or remove heat from specific trays without diluting the process stream. The trays are applicable to absorbing, stripping or heat-sensitive distillation processes. The surface of the Thermagrid tubes acts like that of the bars of a Turbogrid tray, forming a contact section for the liquid and vapour. The tubes can be round, oval or square, according to the needs of the process, and they can be supplied in most materials. Those of adjacent trays are placed at right angles to each other. It is claimed that good heat-transfer rates are obtained from the outside surfaces of the tubes due to intense agitation caused by the surfaces being bathed in a recirculating stream of liquid and scrubbed by the upcoming gases. Trays of the Thermagrid type are being used successfully in America for fatty-acid distillation where the product is particularly heat sensitive. The production of nitric acid and formaldehyde are two of many



other possible applications. The makers say that a column embodying Thermagrid trays has a longer capacity than one of similar diameter containing bubble-cap trays. Moreover, the Thermagrid tray eliminates the need to use superimposed coils or product recirculation when incorporating heat transfer in diffusional processes. A pilot plant is being set up for the purpose of compiling heat and mass transfer data about the tray. **Metal Propellers Ltd., 74 Purley Way, Croydon, Surrey.**

BCE 1250 for further information

New Coating Material

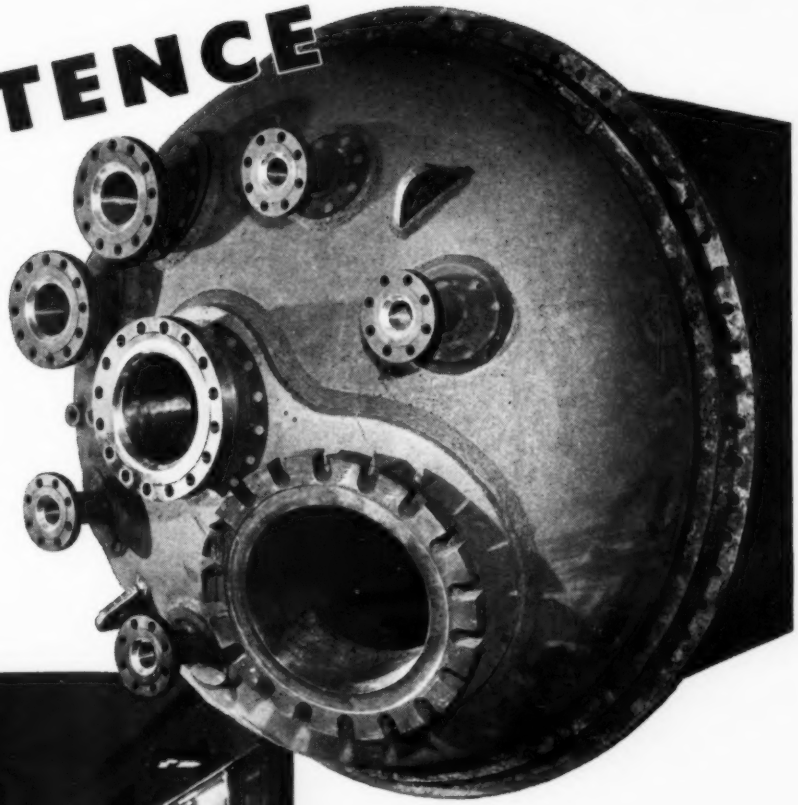
Pilot trial samples of Scopon 1200M, an epoxyester modified with vinyl toluene, are available from Styrene Co-polymers. Suggested uses for the product are in quick-drying hard finishes that are required to be resistant to chemical action. The material contains 32% of vinyl toluene and blends with alkyd resins. **Styrene Co-polymers Ltd., 1 Roebuck Lane, Sale, Cheshire.**

BCE 1251 for further information

Newly Available Mills

The Wheeler fluid-energy mill is being imported into Britain under an agreement recently made between Kek, of Manchester and C. H. Wheeler, of Philadelphia, U.S.A., and negotiations concerning the manufacture of the machine by Kek are under way. The machine works in a vertical plane, the raw material entering at an inlet hopper at the base of the mill and being discharged through classifier vanes at the opposite end of the circuit. Nozzle inlet-

COMPETENCE



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Designed for a working pressure of 500 lbs./sq. in.

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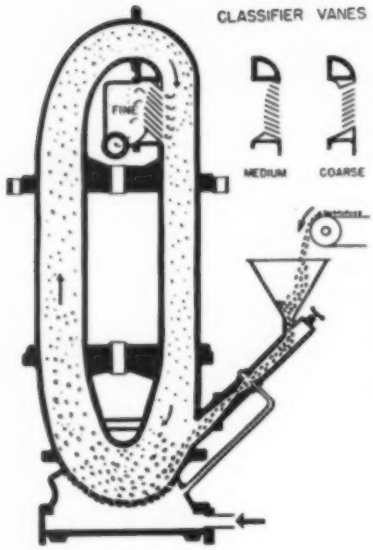

pressure is from 75 to 200 psig, and the mill will function at temperatures from below zero to 1000°F. The machine's capacity is from 500 to 1000 lb. of material an hour. Kek have also brought out a small pin disc grinder designed for laboratory and pilot-plant use in testing batches of new products. The rotor revolves at speeds up to 15,000 r.p.m., considerably faster than in larger models, the drive is belt from an electric motor, and the output is stated, conservatively, to be 30 to 40 lb. an hour. **Kek Ltd., Palmeston Street, Ancoats, Manchester, 12.**

BCE 1252 for further information

Petrol-driven Stirrer

A portable petrol-engine-driven stirrer specially suitable for use in drums in open situations is being manufactured by Kestner. It is made in one unit and is clamped on to the container of the liquid to be stirred. Its two-stroke engine develops 1½ h.p. and is connected to a reduction gear to give a shaft speed appropriate to the type of blade used and agitation required. Sufficient fuel is contained in the tank for up to four hours' running. The engine is fitted with a neat lanyard-type starting device. **Kestner Evaporator & Engineering Co. Ltd., 5 Grosvenor Gardens, London, S.W.1.**

BCE 1253 for further information

A 6-in. High-speed Mill

Premier Colloids are introducing a 6-in. multi-purpose mill—a development from their 3-in. mill made available last year. In principle it resembles the smaller model, but more water cooling is embodied and higher rotor speeds (up to 4000 r.p.m.) are used. The drive is by belt from a motor installed beneath the mill. The machine may be dismantled easily for cleaning. **Premier Colloid Mills Ltd., Hersham Trading Estate, Walton-on-Thames, Surrey.**

BCE 1254 for further information

LOW TEMPERATURE DISTILLATION

The Low Temperature Group of the Physical Society held an all-day discussion on low-temperature distillation in London recently. Below is a summary of some of the proceedings

A DISTILLATION column packing of stamped aluminium sheet was described by G. G. Haselden and A. Wahhab. As the H.T.U. values for different angles of inclination of the packing and for variation of vapour velocity varied from 2 to 4 in. and vapour velocities normally would be about 1½ ft/sec., a column constructed of these packings, therefore, would have the advantage of being very much shorter than one employing perforated plates or bubble caps. One of the problems to be solved was that of liquor distribution. It was expected that the packing would be used for low-temperature distillation, in particular for the section of the column below the feed point. The packing is suitable only for relatively clean fluids. Its ends can be rolled up, thereby making unnecessary any form of edge seal.

Producing Deuterium

W. H. Denton discussed two basic methods for producing deuterium which were under consideration by the U.K.A.E.A. The first was based on ammonia synthesis products, and the second employed a closed-cycle system with hydrogen circulation from which deuterium is separated. The hydrogen recycle process was considered to be the more economic, although there were several formidable design problems to overcome. In the distillation of hydrogen itself there is no difficulty other than that associated with the low density of liquid hydrogen. The separation of deuterium from hydrogen—gases of boiling points 20.8 and 21.5°K respectively—involved mechanical difficulties on account of the low density of liquid hydrogen. For a feed rate of 1000 m^3/hr of hydrogen, a column of about 10 ft in diameter is necessary, and if a 30% deuterium product is to be separated then 90 plates would be required. A feature of the flow diagrams is the extent of use of both reversing and regenerative heat exchangers. The main cold producer is an expansion turbine. To avoid having to use a turbine of small size and one with an extremely high speed of shaft rotation, were the turbine to operate at a temperature of 20-21°K, the refrigeration load is divided into two stages; the upper stage is about 50°K, which allows the turbine rotor to be about 2 in. in diameter, instead of ·24 in., and its speed of rotation 15,000 rpm instead of 200,000 rpm.

K. C. Smith outlined the influence of irreversible effects upon the thermodynamic efficiency of air distillation from the simple formula

$$W_{rev} = \triangle H - T_o \triangle S_{rev}$$

From another simple formula he was able to calculate the minimum work for a separation assuming minimum reflux; thus the ordinary air distillation processes cannot be more than 63% efficient assuming reversible conditions. In practice, where there are temperature differences in the condenser and the re-boiler and where the reflux is to be greater than the minimum, there is a considerable drop in efficiency. Thus, for a 2°C temperature difference at condenser and re-boiler and for a reflux ratio 20% in excess of minimum, the efficiency drops to 40%. The author had compiled a table showing the effect of different design factors upon the efficiency. He suggests a factor of 3.11 for the ideal case. For an actual case, taking into account temperature difference at re-boilers, pressure drop across the distillation column trays, heat leakage into the plant, poor liquid and rich liquid expansion, the factor comes to 4.90. He showed that a gas plant would operate at something like 38% efficiency compared with 63% of a liquid oxygen plant. Introducing a stream of liquid air, known as Lachmann air, into the up column produces an efficiency at a gas plant of 63%.

Design Efficiency

In investigations on methods of estimating the number of contacting stages in the low-temperature distillation process, B. Curry and Miss V. M. Smith had sought primarily a means of comparing efficiencies of designs. They had examined the methods of McCable and Thiele; Ponchon and Savarit; Sorel and Lewis; Lewis and Matheson; Smoker; and Underwood. Finally, they had modified Sorel's method by assuming that the molal overflow at a given plate was directly proportional to the oxygen concentration on that plate. The assumption is not very far from the truth for a double column. In the calculation using it, the terminal flow rates are obtained by heat and mass balances at either end of the column and the liquor rate at each section obtained from a simple linear equation connecting liquor rate and oxygen concentration using known values of equilibrium constants.

The authors invariably calculated argon composition and never attempted to obtain it by difference. A useful consequence of calculations they carried out was that it had been possible to improve old plants by filling them with argon-rich side-streams. Although, the authors said, the prime aim had not been accuracy, in practice the actual and estimated argon concentrations agreed very closely.

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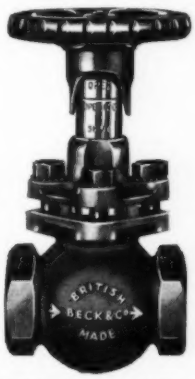

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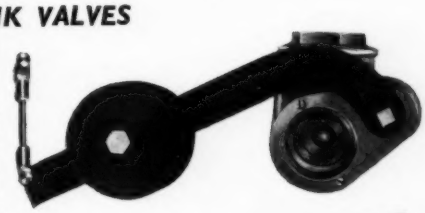

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The Month's News in Brief

A United Kingdom economic, technical and goodwill mission to the Canadian petroleum and allied industries wil arrive in Canada in May and will cross from east to west, visiting all important oil installations and companies in the Dominion. The main object of the mission is to examine all means of promoting and increasing sales of British-manufactured engineering products to these vast and growing industries. The mission, sponsored by the Council of British Manufacturers of Petroleum Equipment, will be led by Mr. J. M. Storey, managing director, Dewrance & Co. Ltd. Mr. G. L. Hancock, director, David Brown Industries Ltd., is deputy leader and the remainder of the mission, which is limited to a total of twelve, is made up of the following companies: British Thomson-Houston Export Co. Ltd., Coventry Gauge & Tool Co. Ltd., I.V. Pressure Controllers Ltd., Imperial Chemical Industries Ltd., Metropolitan-Vickers Electrical Export Co. Ltd., F. Perkins Ltd., Petbow Ltd., Steel Equipment Co. Ltd., Winn & Coales Ltd. and Yorkshire Copper Works Ltd. The mission will be in Canada for approximately three weeks, and on its return will issue a comprehensive report of its journey.

Birwelco Ltd., British manufacturing licensees for Petro-Chem Iso-Flow fluid heating furnaces, have been awarded a contract for the supply of equipment to be used in Esso's butadiene plant at Fawley, Hants. The largest unit will consist of a specially designed Petro-Chem Iso-Flow furnace with a heat release of 192 million Btu/hr. Standing 180 ft high, the heater will be the largest Petro-Chem Iso-Flow furnace in use in the British Isles. Included in the contract are three smaller heaters and a quantity of heat exchange equipment to be supplied by Birwelco's associate company, Brown Fintube Great Britain Ltd. The value of the contract is approximately £250,000. Foster Wheeler Ltd. are responsible for the engineering and construction of the butadiene plant.

The Board of Trade has for disposal upwards of 3000 tons of tungsten ores. The Board's trading stocks have been virtually disposed of during the last few years, and limited quantities from its strategic stocks are available for disposal. The total amount at present available for disposal is about 500 tons metal content. The Board's selling agents, British Tungsten Ltd., have instructions to dispose of this quantity gradually, as required, so as to avoid undue disturbance of the market. The Board reserves the right to refuse offers, whether for prompt or longer-term delivery, at prices which it considers unsatisfactory. Sales from the Board's stocks for prompt delivery have been made at a premium over the maximum quoted market price. The Board wishes to make it clear that it reserves the right to vary the premium at any time.

Brunei Shell Petroleum Co. Ltd., the new Shell Group company registered in Brunei at the beginning of this year, is now working on its own account and the British Malayan Petroleum Co. Ltd., registered in the United Kingdom, will go into liquidation. In effect, operations will continue unchanged, as will the directorship. The effective date of the transfer of the business was January 1, 1957, but, in consequence of the need to complete various legal formalities, the actual transfer of the day-to-day business took place on March 15.

British Railways are making special arrangements for B.I.F. buyers from May 6 to 17. A special B.I.F. train will leave Euston daily at 8.55 a.m. and will run direct to the Fair at Castle Bromwich. The train will take 2 hours 23 minutes. It will leave the Fair at 5.10 p.m. and arive at Euston at 7.48 p.m. Overseas buyers will be able to fly direct from London Airport to Birmingham by feeder services. Buses and taxis will proceed to the Fair from Birmingham Airport in 20 minutes.

Marchon Products' chairman, Mr. F. Schon has announced that his company's exports are now twenty times greater than they were in 1950. Mr. Schon believes that this achievement was attained by frequent visits to most parts of the world by senior executives, by careful study of what the buyer wants, and by prompt delivery of the right goods at the right price. Marchon Products are a member of the Albright & Wilson group.

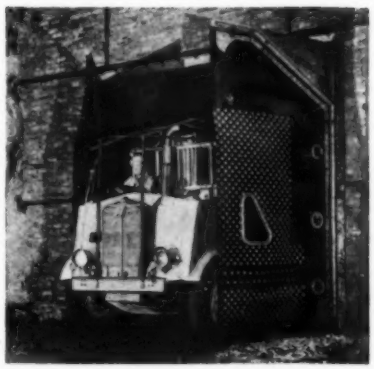
The Institution of Chemical Engineers' 33rd 1957 examination will be held in London and Manchester and at centres overseas, depending on the location of candidates as follows:

Part 1		
Paper A.	September 10,	10 a.m. to 1 p.m.
Paper B.	„ „	2 p.m. to 5 p.m.
Paper C.	September 11,	10 a.m. to 1 p.m.
Paper D.	„ „	2 p.m. to 6 p.m.
Part 2		
Paper E.	September 12,	10 a.m. to 1 p.m.
Paper F.	„ „	2 p.m. to 5 p.m.
Paper G.	September 13,	10 a.m. to 1 p.m.
Paper H.	„ „	2 p.m. to 5 p.m.

Examination entrance forms, returnable not later than June 1, may be had on application to the General Secretary, The Institution of Chemical Engineers, 16 Belgrave Square, London, S.W.1.

W. J. Fraser & Co. Ltd. have recently added a new wing to their design and engineering offices at Harold Hill, Romford, Essex, the building is part of an expansion programme which includes the experimental building, for pilot-scale process testing recently put into operation.

The Tube Investments subsidiary, Mange Plastics Ltd., with works in Fulham, London, will shortly open a new factory at Aston, Birmingham, where the major part of its production will be centred. The new works will treble the company's capacity, and provide facilities for the manufacture of a recently developed range of fittings for plastic tubing.



These special, steel-studded, rubber swing doors have been installed to control air movement in I.C.I.'s Billingham anhydrite mines. The doors were made by Mancuna Engineering Ltd., of Denton, Manchester, and, measuring 13 ft 8 in. wide by 13 ft high, are among the largest in Great Britain.

Elliott Brothers (London) Ltd. announce the conclusion of a licence agreement with the Industrial Instrument Corporation, of Odessa, Texas, for the manufacture and sale of the I.I.C. differential pressure flowmeter in Great Britain.

Orders worth nearly £¼ million for plastic machinery have been placed with Burtonwood Engineering Co. Ltd., of Burtonwood, Warrington, Lancashire, from Australia, India and Japan.

The new orders follow immediately upon the completion of work worth £200,000 for the Texas Eastman Co., Spencer Chemical Co. and Petrochemicals, all of the United States. In addition, the company is supplying equipment to French and Italian firms.

About 60,000 unskilled labourers in the heavy chemical industry will receive an extra 2¼d. an hour (1¾d. for women). This was agreed at a meeting of the Joint Industrial Council for the industry. The agreement will cost companies in the Association of Chemical and Allied Employers some £1½ million a year. The new basic rates will be £8 3s. 2d. (men) and £5 15s. 0¼d. (women) for the standard week.

A new company, Chemical Process Development Ltd., of 220-222 Elgar Road, Reading, Berkshire, has been formed to meet the demand for small-scale and pilot-plant work. Steam-raising and other plant is available on site.

The English Electric Co. Ltd. announces that it has received an order from the Admiralty for the design and manufacture of the main propelling steam turbines and condensers for Britain's first nuclear-powered submarine. This order covers the prototype

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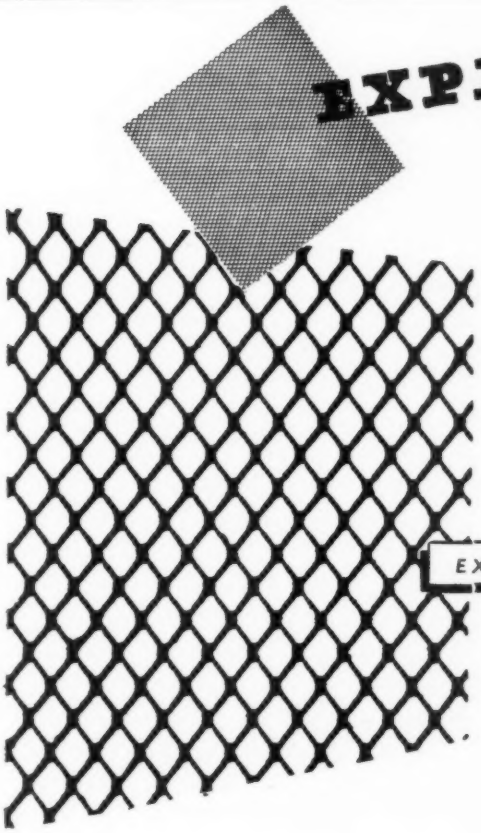

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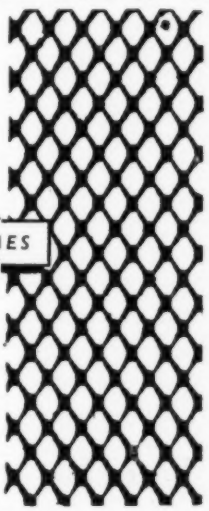

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machinery, which will be tested in a land-based hull, and also the turbines to be installed in the first seagoing submarine.

The headquarters offices of the British Institute of Management and the Institute of Industrial Administration, at present at 8 Hill Street, London, W.1, will be transferred in the latter half of May to specially planned premises at 80 Fetter Lane, E.C.4. The move is part of the scheme for reorganisation of the two bodies into one Institute. The Institute of Personnel Management will also take offices in the new Management House.

We regret that the photograph of Whessoe W-D Electro-Detarrers installed by Woodall-Duckham Construction Company Ltd., as part of the Avenue Carbonisation and Chemical Plant for the National Coal Board, was used in error as an illustration for the article "Electro-Precipitators in the Chemical Industry" published in our February issue.

On and after April 7, 1957, the telephone number of the Scottish office of Wild-Barfield Electric Furnaces Ltd., at 147 Bath Street, Glasgow, C.2, will be CITy 4878.

The merger was recently announced of two nuclear instrumentation companies: Isotope Developments and R. A. Stephen & Co. Mr. W. W. Hill-Wood, chairman of Isotope Developments, has become chairman of R. A. Stephen, and Mr. H. A. Luss and Mr. G. A. Thick, joint managing directors of Isotope Developments, have also joined the Stephen board.

The Third International Instrument Show, sponsored by B. & K. Laboratories Ltd. and Allied International Co. Ltd., was staged at Caxton Hall, Westminster, from March 25 to 29. Over fifty leading instrument manufacturers from the U.S.A., Switzerland, West Germany, Denmark, Holland, Sweden, Austria and Great Britain displayed some three hundred items of test equipment and apparatus.

A complex 30-ton stainless-steel container for Britain's first full-scale fast-breeder reactor left John Thompson's works at Wolverhampton on April 5 for Dounreay, on the north coast of Scotland, where it will be installed along with liquid-metal heat-exchange systems and boiler plant manufactured by the same company. The container is probably the most complicated stainless-steel vessel ever fabricated anywhere in the world and took eighteen months to build. Its overall dimensions are some 20 × 14 ft, and the complex control rod tubes, instrument pipes, rotating shields and inner components of the vessel have been positioned and welded to thousandths of an inch. More than 3500 X-ray negatives were taken to ensure that every welded joint is absolutely leak-proof.

A cast of sixty-five tons of titanium-bearing steel—twice the quantity ever produced before by a single furnace in Britain—was made recently in the large arc furnace at Samuel Fox, a subsidiary of United Steel. Titanium-bearing stainless steel is difficult to produce in an arc furnace to very low carbon specifications, but by careful planning, close timing and temperature control, the 65-ton cast was tapped successfully at the end of an eight-hour shift. After rolling into sheet and strip, the steel will be supplied to the makers of atomic energy and chemical plant and to other industries.

Henry Balfour & Co. Ltd. have announced that they are to erect a major research and development laboratory at Leven to serve their entire group of associated companies. The new project will be devoted to the research and development of chemical and chemical engineering plant. A 25-acre site adjoining the company's Leven works will house, by June, 1958, a group of units which will cover the full range of their development interests.

In the official acceptance test on the Simon-Carves electro-precipitators at the National Coal Board's "Phurnacite" plant at Aberaman, South Wales, an efficiency of 99.93% was obtained. This is believed to be the highest test efficiency ever recorded on a dry-type electro-precipitator in this country.

Heat Transfer Ltd. announce the appointment of W. B. P. Coleman Ltd., 29 Oxford Street, Newcastle upon Tyne, as the company's north-eastern agents, and McCulloch & Miller, 180 West Regent Street, Glasgow, C.2, as agents for Glasgow and its environs.

Sir Graham Cunningham, chairman of the Triplex Group, recently announced the appointment of the Machine Tools Division of George Cohen, Sons & Co. Ltd. as sole world agents for "Eldair" alligator shears.

All electrical measuring instruments for HERMES (Heavy Element Radioactive Material Electro-magnetic Seperator), the new isotope separator at Harwell, were manufactured and supplied by Ernest Turner Electrical Instruments Ltd., High Wycombe, Bucks.

Morgan Crucible Co. Ltd. have installed a Hec general-purpose computer in their Battersea head office. The computer, made by the British Tabulating Machine Co. Ltd., is expected to pay for itself in a maximum of five years.

Metropolitan-Vickers have announced that a new irradiation laboratory is being set up at the company's Barton Works. This is now being equipped with a 4-MeV linear accelerator.

The Metal Box Co. Ltd's head office address is now 37 Baker Street, London, W.1, telephone HUNter 5577.

Meetings of the Month

The Society of Instrument Technology

April 17. *Newcastle Section:* At King's College, Stephenson Building, Newcastle, 7 p.m. "Data Read-out Equipment and Possible Applications to Process Control", by A. St. Johnston.

May 14. *Manchester Section:* At Manchester College of Technology, 7.30 p.m. "Industrial Applications of Radio-isotopes", by H. A. Tapsfield.

The Institution of Chemical Engineers

April 26. *Graduates and Students Section:* At the Cora Hotel, Upper Woburn Place, London, W.C.1. 9.15 a.m. A symposium on "The Impact of Atomic Energy on Chemical Engineering".

Society of Chemical Industry

May 14. *Chemical Engineering Group:* At 14 Belgrave Square, London, S.W.1. 5.30 p.m. "Some New Chemical and Physical Aspects of Polyester Resin Technology", by L. H. Vaughan.

Institution of Mechanical Engineers

April 17. *Industrial Administration and Engineering Production Group Discussion:* At 1 Birdcage Walk, Westminster, London, S.W.1. 6.45 p.m. "The Importance of Internal Communications in an Engineering Works".

April 25. *Steam Group Discussion:* At 1 Birdcage Walk, Westminster, London, S.W.1. 6.45 p.m. "Removal of External Deposits on Boilers".

April 30 to May 2: At 1 Birdcage Walk, Westminster, London, S.W.1. April 30, 6 p.m. May 1, 10 a.m. and 2.30 p.m. Informal discussion. 6 p.m. May 2, 10 a.m. and 2.30 p.m. "Conference on Metals Under High Rates of Strain".

The Institute of Metals

April 30, *Metal Physics Section:* At Church House, Great Smith Street, London, S.W.1. 2.30 p.m. A discussion on "The Metal Physics of Corrosion and Oxidation". Discussion will be opened by Dr. O. Kubaschewski (National Physical Laboratory) and Dr. C. Edeleanu (Tube Investments Research Laboratories).

May 1. At 17 Belgrave Square, London, S.W.1. All-day symposium on "Metallurgical Aspects of the Control of Quality in Non-ferrous Castings", in association with the Institute of British Foundrymen.

Forthcoming Exhibitions

Home

April 29. *The Fifth Factory Equipment Exhibition:* At Earls Court, London, until May 4.

May 6. *British Industries Fair:* At Castle Bromwich, Birmingham, until May 17.

May 7. *Instruments, Electronics and Automation Exhibition:* At Grand Hall, Olympia, London, until May 17 .

May 13. *First Protective Clothing and Safety Equipment Exhibition:* At Empire Hall, Olympia, London, until May 17.

Overseas

April 27. *The Ninth International Liége Fair:* At Liége, until May 12.

April 27. *The Forty-first Swiss Industries Fair:* At Basle, until May 7.

April 27. *The Thirty-first International Industries Fair:* At Brussels, until May 12.

April 28. *German Industries Trade Fair:* At Hanover, until May 7.

April 29. *National Materials Handling Exposition:* At Philadelphia, until May 3.

May 14. *The Fourth International Packaging Exhibition:* At Amsterdam, until May 21.

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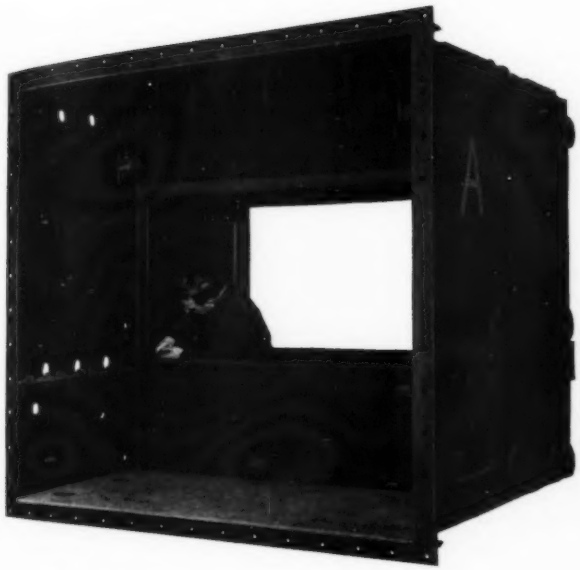

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People in the News

G. & J. Weir Ltd. announce the appointment to the board of directors of the Weir Group of **Mr. James Alexander Lumsden**, of Maclay, Murray & Spens, Glasgow solicitors. Mr. Lumsden's appointment took effect on March 6, 1957.

Dr. J. W. Bondi, Brigadier L. Bootle-Wilbraham and **Mr. G. H. Diggens** have been appointed directors of Brush Export Ltd. Mr. Diggens has also been appointed a director of National Oil Engines (Export) Ltd.

Mr. F. A. Jackman, who joined Carless Capel & Leonard Ltd. nearly 30 years ago and who was elected to the board of the company in January, 1954, has been appointed assistant managing director.

Mr. J. A. Lamond has been appointed joint managing director of W. H. A. Robertson & Co. Ltd., of Bedford.

In connection with plans for an extensive programme of fundamental research in various branches of chemistry, Pfizer Ltd. announce the appointment of **Dr. R. J. Boscott** as head of chemical research. The new post is stated to be a major appointment.

The following changes in the board of Griffin & George Ltd. have been announced: **Mr. R. McKinnon Wood** has asked to be relieved of his duties as chairman of the company, in view of the important public duties he will assume in the near future as chairman of London County Council. **Mr. H. R. Bettinson**, hitherto vice-chairman, will, for the time being, act as chairman of the board. **Mr. N. McKinnon Wood** has been appointed vice-chairman and relinquishes his appointment as managing director. **Mr. N. Trepte** has been appointed managing director.

Dr. F. Kidd relinquished his post as Director of Food Investigation on March 31, 1957, after nearly 40 years' service with the Department's Food Investigation Organisation.

The Fifth Cadman Memorial Medal has been awarded to **Lord Godber** of Mayfield, chairman of The "Shell" Transport & Trading Co. Ltd., and will be presented to him when he delivers the Fifth Cadman Memorial Lecture on October 24, 1957, in the hall of The Royal Institution, London. Previous medallists have been **Sir William Fraser, R. Price Russell, Dr. R. E. Wilson** and **C. A. P. Southwell.**

Lord Godber.

J. M. Storey.

Mr. J. M. Storey is to lead the engineering mission to Canada sponsored by the Council of the BMPE (see p. 284).

Sir Hugh Beaver, who succeeds Mr. John Oriel as president of the Institution of Chemical Engineers (see "Digest").

Mr. V. Thomas, who for the past year has been general sales manager in charge of all home sales of Fielden Electronics Ltd., has now also accepted responsibility for export activity. Prior to joining Fieldens, Mr. Thomas was employed with Electronic Instruments Ltd.

Mr. K. G. Sinclair has been appointed chairman of Griffin & George Ltd., the laboratory furnishers.

Mr. H. D. Cummins and **Mr. D. O. Hallett** have been appointed sales director and technical director of a new company, Stainless Steel Plant Ltd., Walden Estate, Cocker Street Works, Blackpool. The new company will specialise in the fabrication of stainless-steel plant for the chemical and pharmaceutical, food, brewery and allied industries.

R. C. Dickie.

S. A. Gregory.

Mr. S. A. Gregory has just been appointed technical manager of Audley Engineering Co. Ltd. He will be located at Newport, Shropshire, and will move from Scunthorpe, Lincolnshire, where he held the post of chief of Frodingham research department, Appleby-Frodingham Steel Co.

The Minister of Housing and Local Government, Mr. Henry Brooke, has appointed **Mr. R. C. Dickie**, chief chemist of Marchon Products Ltd., of Whitehaven, to be an additional member of the Standing Technical Committee on Synthetic Detergents.

Auto Diesels Ltd., of Uxbridge, announce a new division within the company. It will be known as the Pump and Hydraulic Machinery Division. This will embrace the existing pump business, in addition to a number of new projects currently under development. **Mr. R. J. Sanders** has been appointed general manager of this division, and has been succeeded as home sales manager by **Mr. Edward Ward.**

Dr. V. G. W. Harrison has been appointed director of research of the Printing, Packaging and Allied Trades Research Association in succession to Dr. G. L. Riddell. He took up his appointment on April 1.

Mr. D. Bradley, who has taken up a management appointment with the development departments of Newton, Chambers & Co. Ltd., as a chemical engineer, began his working life as a junior chemist with Thorncliffe Coal Distillation Ltd. in 1942. He joins the company from the N.C.B., for whom he was laboratory manager at the Avenue coking oven plant, near Wingerworth.

Dr. J. C. Robb has been appointed Professor of Physical Chemistry at Birmingham University.

Sir Thomas Hutton, director of the British Productivity Council, has announced his intention of retiring in the latter part of this year. In 1948, on the formation of the U.K. section of the Anglo-American Council on Productivity, he was appointed general manager, and became director of the B.P.C. on its formation in 1952. He has therefore been associated with the work since the beginning. His successor has not yet been appointed.

The following technical directors have recently been appointed to the board of K.D.G. Instruments Ltd.: **Mr. F. E. Barritt**, works manager, and **Mr. L. R. Pullen**, sales manager.

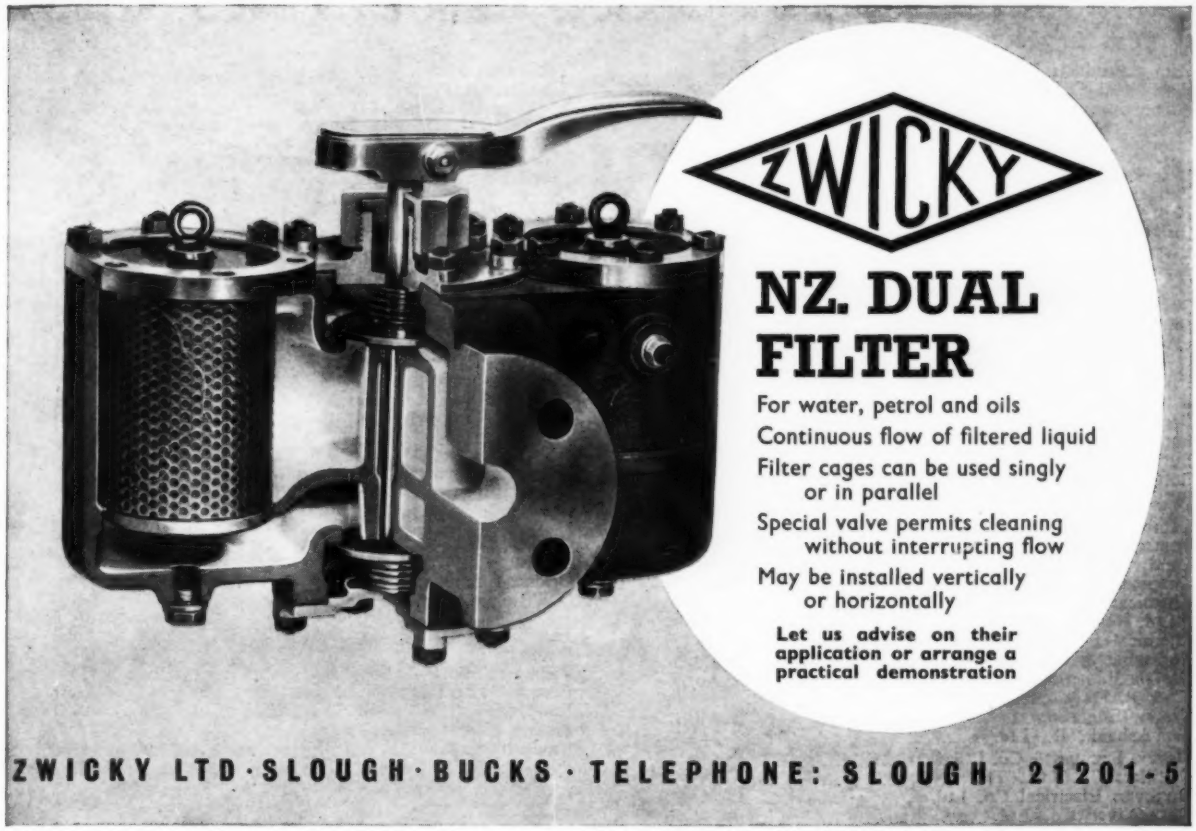
Mr. R. H. E. Thomas, a member of the National Coal Board, has been appointed chairman of the Board's Opencast Executive in succession to **Dr. W. Reid**, who has taken up his appointment as chairman of the Durham Divisional Board. **Mr. H. W. Hembry**, also a member of the National Coal Board, has been appointed deputy chairman of the Opencast Executive.

Sir Ewart Smith has been appointed a deputy chairman of I.C.I. Ltd. The company has two other deputy chairmen, **Mr. A. J. Quig** and **Mr. S. P. Chambers**. Sir Ewart is chairman of the British Productivity Council, a member of the Scientific Manpower Committee, a vice-president of the Institution of Mechanical Engineers, and a member of the Institution of Chemical Engineers and of the Société des Ingénieurs Civils de France. In 1946, Sir Ewart received his knighthood and also the American Medal of Freedom with Palm. More recently, he was elected a Fellow of The Royal Society (see note below).

Sir Ewart Smith.

F. L. Rose.

Fellows recently elected to The Royal Society include: **F. S. Dainton,** professor of physical chemistry in the University of Leeds; **J. K. N. Jones,** professor of chemistry in Queen's University, Kingston, Ontario; **F. L. Rose,** director of research, Imperial Chemical Industries (Pharmaceuticals) Ltd.; **Sir Ewart Smith,** deputy chairman and technical director, Imperial Chemical Industries Ltd.; and **D. N. Wadia,** director, Raw Materials Division, The Department of Atomic Energy of India.



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